Devising a Framework for the Development of the Medium Scale Coal Sector in Colombia

by

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Submitted to the Department of Urban Studies and Planning in Partial Fulfillment of the Requirements for the Degree of Master of Science in the Special Program for Urban and Regional Studies and Planning

at the

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ABSTRACT

The purpose of my study is to devise a framework that encompasses the strategies put forth by the Colombian government as to advancing the productivity and competitiveness of the country, with an emphasis on finding development alternatives for the medium-scale coal sector, tackling its shortcomings, and improving the sector's situation. The framework integrates three dimensions of analysis including the Colombian national policies for productivity and competitiveness, coal sector development, and environmental conservation. I lay out several coal-development alternatives and evaluate their economic and environmental performances using input-output analysis, and multi-criteria decision analysis for alternative selection. I also model different scenarios prioritizing each of the dimensions of analysis.

The results from the scenario analysis show that coal gasification suits best the three dimensions of analysis, providing the highest economic benefits with the least environmental impacts of the proposed development alternatives.

In addition, I use Geographic Information Systems to conduct location-suitability analysis for the coal fields in the interior of Colombia. Results of the suitability analysis portray coal fields in the Córdoba and Cundinamarca Provinces as the most suitable regions for coal-gasification development.

Supervisor: Karen R. Polenske

Reader: Michael Flaxman

Dedicated to my Caring Father, Mother, Brother and Sisters

and to my Beloved Wife and my Daughter.

Their Love and Support made this

Accomplishment possible.

CONTENTS

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I would like to thank my Thesis Supervisor, Professor Karen R. Polenske, for inspiring my interest in studying regional economy and planning, and also for her continuous encouragement and academic excellence.

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In addition, I want to thank the Information and Mining Divisions Staff of the Colombian Mining and Energy Planning Unit – UPME, especially, Engineer Jorge Londoño, for providing valuable information and data for the analyses conducted in this study.

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CHAPTER 1
INTRODUCTION

The capacity of a country to build a strong national productive apparatus and to satisfy the energy requirements that emerge in that process, are fundamental elements to attain development. Further, implementing processes by which the country advances its competitiveness will improve the economic atmosphere and the social conditions of people. These concepts also entail fostering social and economic prosperity, reducing any adverse impacts of development on the environment.

For this study, I focus on Colombia, which has taken steps towards improving its productivity and competitiveness by laying out policies that engage the productive sectors of the country in an integrated sustainable-development-driven program, called the National Agenda for Competitiveness. According to this program, governmental institutions are required to design strategies for the development of Colombia's economic sectors with principles of productivity and sustainability.

For the coal sector, the focus of this study, the Colombian government has implemented some policies intended to promote sustainable mining in the country and to improve the productivity and competitiveness in regions where this sector is underdeveloped. The core of these policies is the model of mining districts, territorial divisions for the stewardship of the mineral resources with the purpose of creating strategies for the advancement of the coal sector. This model presents a unique opportunity for the implementation of development alternatives that take into account the regions' socioeconomic and environmental context.

In Colombia, the coal sector is composed of two main categories: The *large-scale coal sector* is characterized by being very well developed, having economies of scale, and suitability for exports because of their geographical location, enormous production volumes, excellent quality, and low production and transportation costs. The coal is mainly steam coal used for electric-power generation.

The *medium-scale coal sector* has medium to low production levels, lacks continuous local demand, and is inappropriate for exports because the mines are located in the interior of the country; therefore, the huge transportation and production costs do not create economies of scale. Nonetheless the quality and variety of these deposits are remarkable, and the reserves are vast. In this study, I focus on the medium-scale coal-sector.

The purpose of my study is to devise a framework that encompasses the strategies put forth by the Colombian government as to advancing the productivity and competitiveness of the country, with an emphasis on finding development alternatives for the medium-scale coal sector, tackling its shortcomings, and improving the sector's situation. Also, in the process of creating coal-development alternatives, I take into account aspects of environmental sustainability and maximization of benefits for the coal sector and for the economy as a whole, enhancing the contribution of the medium-scale coal sector to the country's socioeconomic growth.

Moreover, the framework sheds light on alternatives for the use of coal that are strategic for Colombia's development and competitiveness, such as projects that ensure the supply of medium and long-term energy requirements. The framework takes advantage of coal's flexibility to be converted into other forms of energy and fuels, like electric power or liquid fuels and gas, whose scarcity is being faced by the country.

I create development alternatives based upon experiences from the United States, where coal conversion into various forms of energy has been performed for several decades (Freudenthal 1974). In addition, I incorporate planning tools for evaluating the economic and environmental performances of outlined alternatives, and selecting the most appropriate coal development alternative from the economic and environmental perspectives.

I use three methodologies: (1) input-output analysis to determine the potential economic impact of each development alternative, (2) spatial analysis using geographic information systems (GIS), and (3) multi-criteria decision analysis to account for several perspectives and factors of decision, like economic and environmental effects, in parallel.

Spatial analysis is included in the framework's analytical section, as GIS may provide a set of valuable information for each development alternative, related to transportation cost and efficiency, and further environmental impacts, which can be included in the multi-criteria decision analysis. However, I did not conduct transportation and environmental GIS analyses in the case-study (Chapter 6), due to the lack of detailed and specialized data required for that purpose.

In this framework, GIS is also intended to plan the implementation of a selected coal development alternative. I illustrate the use of GIS in Chapter 6, by conducting a prototype procedure of spatial analysis on project location suitability, based on the location of inputs, available infrastructure for the supply of inputs and distribution of transformed products.

An essential premise for this framework, is that the medium-scale coal sector, which is located in the interior of Colombia, requires local and constant, long-term demand in order to develop. This allows mining projects to be large enough to achieve economies of scale, countering location and transportation disadvantages for exports and diminishing the impacts of foreign-market volatility. Therefore, I emphasize in the framework the activities that ensure the demand for coal assuming that coal-mining activities will thrive insofar as the demand for coal is in place.

With this framework, I intend to provide the Colombian governmental agencies that make decisions about the coal sector, with a tool for planning and budgeting purposes and to envision the kind of projects that should be fostered by the government. However, the scope of this study and the limited detail of the data that I could acquire in the study's preparation time, do not support major investment decisions. Careful analysis of the recommended coal-development alternatives should be conducted to ensure their viability in the Colombian context and to justify major investments and policy actions.

In Chapter 2 "Framework for the Development of the Medium-Scale Colombian Coal Industry," I provide an overview of the proposed framework for the advancement of the coal sector in line with the strategies for the country's productivity and competitiveness improvement. I describe the assumptions, components, methodologies and outcomes of the framework.

In Chapter 3 "Competitiveness and Productivity Agenda in Colombia," I describe the strategies that the Colombian government has implemented to enhance the productivity and competitiveness of the country. I also discuss the set of policies that governmental agencies managing the mineral resources of the country have put forth to engage the coal-mining sector in the process of competitiveness improvement. In addition, I indicate the coupling of the proposed framework with those strategies.

In Chapter 4 "Colombia's Energy Situation," I present Colombia's energy outlook and analyze the energy situation of the country in the medium and long term, identifying the country's requirements and energy-supply challenges for its future development.

In Chapter 5 "Coal Mining in Colombia," I describe the situation and potential of the coal sector in the country, emphasizing its evolution, the country's vast coal endowment, the constraints for development of the medium-scale coal sector, and also, the remarkable possibilities for its advancement.

In Chapter 6 "Medium-Scale Coal Development Alternatives in Colombia," I illustrate the application of the framework by envisioning and evaluating several coal-development alternatives that could contribute to the sustainable economic development of the coal sector and the country. I evaluate the alternatives using input-output analysis and multi-criteria decision analysis to account for various factors of decision in parallel. After selecting a development alternative, I conduct a prototype spatial analysis using Geographic Information Systems (GIS) for project location suitability in coal regions.

In Chapter 7 “Conclusions,” I present a summary of the thesis, the proposed framework, its outcomes, and its usefulness for assisting the governmental institutions in the planning of development strategies for the coal sector. I also comment on further work that can be done from this study.

I hope this framework becomes a practical tool for planning in the coal sector, helping effectively the sector’s and the country’s development.

CHAPTER 2

FRAMEWORK FOR THE DEVELOPMENT OF THE MEDIUM-SCALE COLOMBIAN COAL INDUSTRY

The motivation of this thesis is to create a framework for the Colombian medium-scale coal sector to assist the country's decision-makers in finding development alternatives for that sector. I conceived this framework to integrate the current policies of the Colombian National Government for the advancement of the productivity and competitiveness of the country, environmental conservation, and smart use of the country's coal resources.

In the development of this framework, I emphasize finding development alternatives that improve the medium-scale coal sector's situation. Also, in the process of envisioning coal-development alternatives, I take into account aspects that are environmentally sustainable and that benefit the coal sector and the economy as a whole, as a means to increase the contribution of the medium-scale coal sector to the country's sustainable socioeconomic growth. The analyses comprise several policy decision factors and different scenarios reflecting prioritization cases, in order to find the most appropriate alternative for the development of the coal sector, the country's economic growth, and environmental conservation, altogether.

2.1 Framework Overview

The framework accounts for three analysis dimensions, namely (1) the Colombian national policies for productivity and competitiveness, (2) the coal sector development, and (3) sustainability or environmental conservation. For the coal-development alternatives, I take into account what is important for each dimension.

2.1.1 Dimensions of Analysis

In this section, I provide an explanation of the dimensions of analysis. These dimensions are categories of factors that I consider for the study and the basis of the framework.

1. Colombian National Policies for Productivity and Competitiveness Dimension

For this dimension, I consider the effort that the Colombian government is undertaking to make the country competitive and to improve the socioeconomic conditions for people. I urge Governmental institutions to create strategies for the sustainable and effective development of the country's productive sectors they manage. Further, strategies should be coordinated among sectors to aim at the same objective.

For the coal sector, the Colombian government, through the Mining and Energy Ministry, has created policies attempting to promote the mining activities and to improve the productivity and competitiveness of the medium-scale coal sector in an environmentally sustainable way. Coal-development alternatives must be attuned to the government's efforts and must ensure an increasing contribution of the coal sector to the national development. In addition, coal-development alternatives can supply products that are strategic for the country's competitiveness and advancement, like energy in the form of power or fuels.

In this framework, I consider a scenario in which the priority is the economic benefit stemming from the coal alternative developments.

2. Coal-Sector Development

The coal sector in Colombia presents deep disparities: while the country is the fourth largest global steam coal exporter (WCI 2008), most of the coal mining in the interior of the country is poorly developed, despite having a great potential for expansion and for advancing the socioeconomic conditions of regions. Coal-development alternatives must ensure a continuous demand for coal in a way that medium-scale coal-mining projects achieve economies of scale to overcome development constraints and improve its productivity and output and environmental performance. I provide a further description of the medium-scale coal sector in Chapter 5.

In this framework, I evaluate the activities that ensure the demand for coal rather than analyzing coal-mining development, assuming that coal-mining activities will thrive insofar as there is a continuous, long-term demand for coal. In sum, this is a demand-driven analysis for the medium-scale coal-sector development.

Moreover, in the analysis of coal-development alternatives, I consider a scenario in which the coal-sector development is prioritized.

3. Environmental Conservation

Reduction of the adverse impacts of development, and environmental protection, are fundamental for sustainable development. Currently, to implement and to oversee pollution controls in medium- to low-yield coal mines is a challenging process. A large coal mining development, as the proposed in this study, would allow the government to design and implement environmental controls in an early stage of development.

The implementation of coal-development alternatives implies the introduction of pollution controls intended to improve the present environmental performance of coal mining and processing activities in the country. Therefore, environmental performance of the proposed coal-development alternatives must be taken into consideration in order to balance the environmental footprint of the medium-scale coal sector's development. I do this in the framework by accounting for emissions of carbon dioxide (CO_2) and water consumption of each alternative. I also consider a scenario that prioritizes environmental conservation, giving a high importance to environmental performance.

2.2 Framework Methodology

I provide a brief description of the framework´s process and methodologies below. In Chapter 6, I present a case study to show how the framework works.

I started the analysis by finding possible coal-development alternatives that comply with the dimensions of analysis described in the previous section, from development alternatives analyzed in Wyoming State of the United States

(Freudenthal 1974), including intensification of coal-based power generation, coal liquefaction, and coal gasification.

Then, I researched the economic and environmental performance of each alternative from comprehensive studies conducted by the U.S. Department of Energy (U.S. DOE). Investment and environmental data for each reference plant of the alternatives from the U.S. DOE had different scales of production and coal consumption. For analysis and comparison purposes, I assumed constant returns to scale to adjust the plants' levels of investment, coal consumption, production, and environmental impacts, for a consumption target of 4 million tonnes a year, which is the scale I assume for the coal-mining development associated with any of these projects.

After I normalized the development alternatives to the target coal consumption, I used input-output analysis to evaluate the direct, indirect, and induced effects of each development alternative investment on the coal-sector output, the country's total output, and income. Further, I converted the economic and environmental performance values of the development alternatives into performance indexes for easier interpretation and analysis.   Furthermore, I used a multi-criteria decision methodology and scenario modeling to identify the level of benefits that development alternatives would generate in different priority scenarios for development.

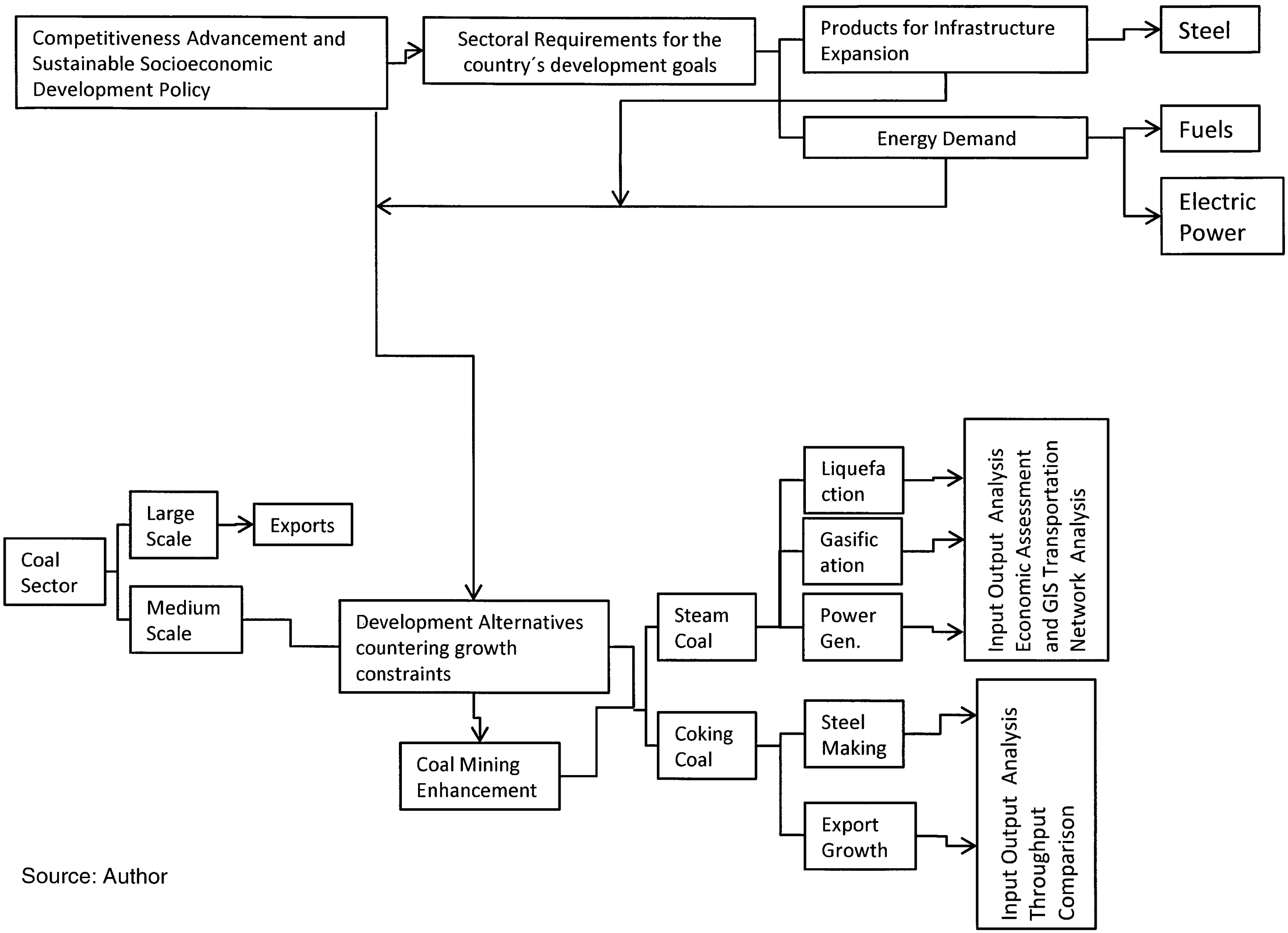
With this set of information, decision-makers can chose an alternative development according to a given priority, i.e., economy, development of the coal sector or the environment. In the case study of Chapter 6, I selected the coal-development alternative with the best overall performance.

Spatial Analysis

I include GIS in the analysis, as it may provide a set of valuable information for each development alternative, related to transportation cost and efficiency, and further environmental impacts, which can be included in the multi-criteria decision analysis. However, I did not conduct transportation and environmental GIS analyses in the case study, as I was missing detailed and specialized data required for that purpose.

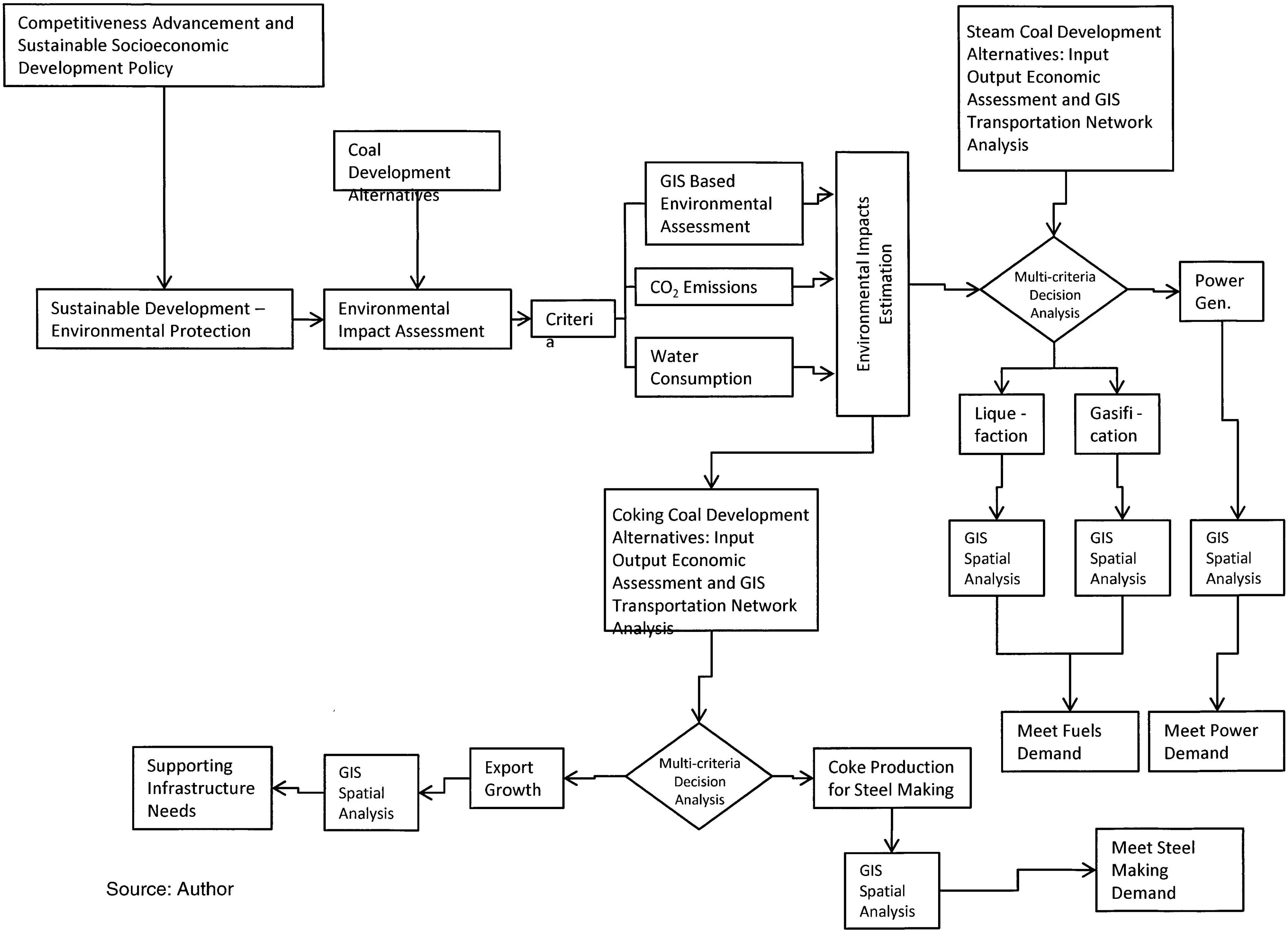
After I selected a coal-development alternative, I used Geographic Information Systems (GIS) to conduct the spatial analysis. This kind of analysis is useful for planning the development alternative selected, and the identification of optimal locations, required supporting infrastructure, inputs sourcing, and output allocation.

I present a block-flow model in Figures 2.1 and 2.2 to summarize and illustrate the framework's functioning. The flow model starts from the three dimensions of analysis described, and considers the fundamental elements for each dimension. Further, the flow model describes the factors of decision and the analysis methodologies used for evaluation of alternatives. Finally, the multi-criteria decision analysis provides an understanding about the kind of development that should be fostered in the country, and GIS analysis is used to plan the development strategy.



Source: Author

Figure 2.2: Block-Flow Diagram: Framework for Development of the Colombian Medium-Scale Coal Sector (Cont'd)



Source: Author

Figure 2.1: Block-Flow Diagram: Framework for Development of the Colombian Medium-Scale Coal Sector

CHAPTER 3

COMPETITIVENESS AND PRODUCTIVITY AGENDA IN COLOMBIA

In 2004, the Colombian National Commission for Economic and Social Policy (CONPES) put forth the National Competitiveness and Productivity Policy: Communitarian State - Development for Everyone. This Policy established priorities, strategies, institutions in charge, and timelines from regional and sectoral perspectives for the coordinated and integral achievement of the country's competitiveness through higher productivity and more efficient use of resources with principles of social and environmental responsibility (Conpes 2008).

This Policy is materializing with the design and application of the National Agenda for Competitiveness, which is currently under construction and whose main basis is the consensus among the government, the private sector, the academia, the territorial authorities, the institutions, and the Colombian Society in general, to undertake the reforms, programs, and strategic projects critical for improving the productivity and competitiveness in Colombia (Confecámaras 2005).

The National Agenda is intended to be a bottom-up process of experience-gathering and coordinated construction of strategies by different sectors of the Nation to attain sustained economic growth, technological advancement, poverty alleviation, and social development. This inclusive scope entails the implementation of productivity and competitiveness policies and strategies by the governmental institutions in charge of the Nation's sectors, incorporating the interaction among them for the accomplishment of the National Agenda's objectives.

3.1 The Colombian Government's Role in the Coal-Mining Sector

In 2001, a new National Mining Code was implemented in Colombia. The conception of the Government's role shifted from being the main investor, manager, and developer of the mining business to being a promoter, facilitator, and comptroller of the use of mineral resources. Therefore the investment and development of mineral mining and transformation projects were left for the national and international private sectors (UPME 2006).

3.2 Competitiveness Agenda for the Mining Sector

For the Mining Sector, the preparation, execution, and observation of such policies, are under the jurisdiction of the Mining and Energy Ministry. They should be consistent with the Government's role in the Colombian Mining Industry (Promoter, Facilitator, and Comptroller), and the principles of the National Agenda, which for the mining sector translates into achievement of sustainable advancement of mining activities and expansion of the mining sector's share of the national output.

Policies made by the Ministry in this context include: Promotion of Mining, Management of Mining Resources, and Improvement of the Productivity, and Competitiveness of the Mining Sector.

3.3 Mining Sector's Competitiveness Policies

The **Promotion of Mining** policy is intended to consolidate the mining industry in Colombia and attract national and foreign investment to develop mining projects of national interest across the country. As explained in Minminas (2005), these new projects, undertaken in a sustainable manner and in harmony with the cultural and social contexts of regions, will generate growth and wellbeing due to the smart and transparent distribution of royalties and the demand for products and services provided by local suppliers

The **Management of Mining Resources** policy is meant to optimize the performance of institutions that assign and oversee the Mining Concessions and manage the Nation's mineral resources. This translates into a more effective, efficient, and transparent concession-bidding process and contract oversight.

The policy on **Improvement of Productivity and Competitiveness of the Colombian Mining Sector** is intended to specialize and strengthen the economies of scale of the mining activities in order to increase the sustainable use of mineral resources by regions. In this approach, regions are able to structure plans of social and economic development integrated to the proper use of their mineral resources.

The main component of this strategy is the Model of Mining Districts, which allows the local agents of each district to reinforce their action capacity on the regions, engaging territorial institutions to design and implement programs and projects based on smart use of mineral resources, bolstering regional development and enhancing the living conditions of communities without compromising the environment (Minminas 2007).

In order to understand the context of the strategy's development, I present a further explanation of the Mining Districts rationale in section 3.4.

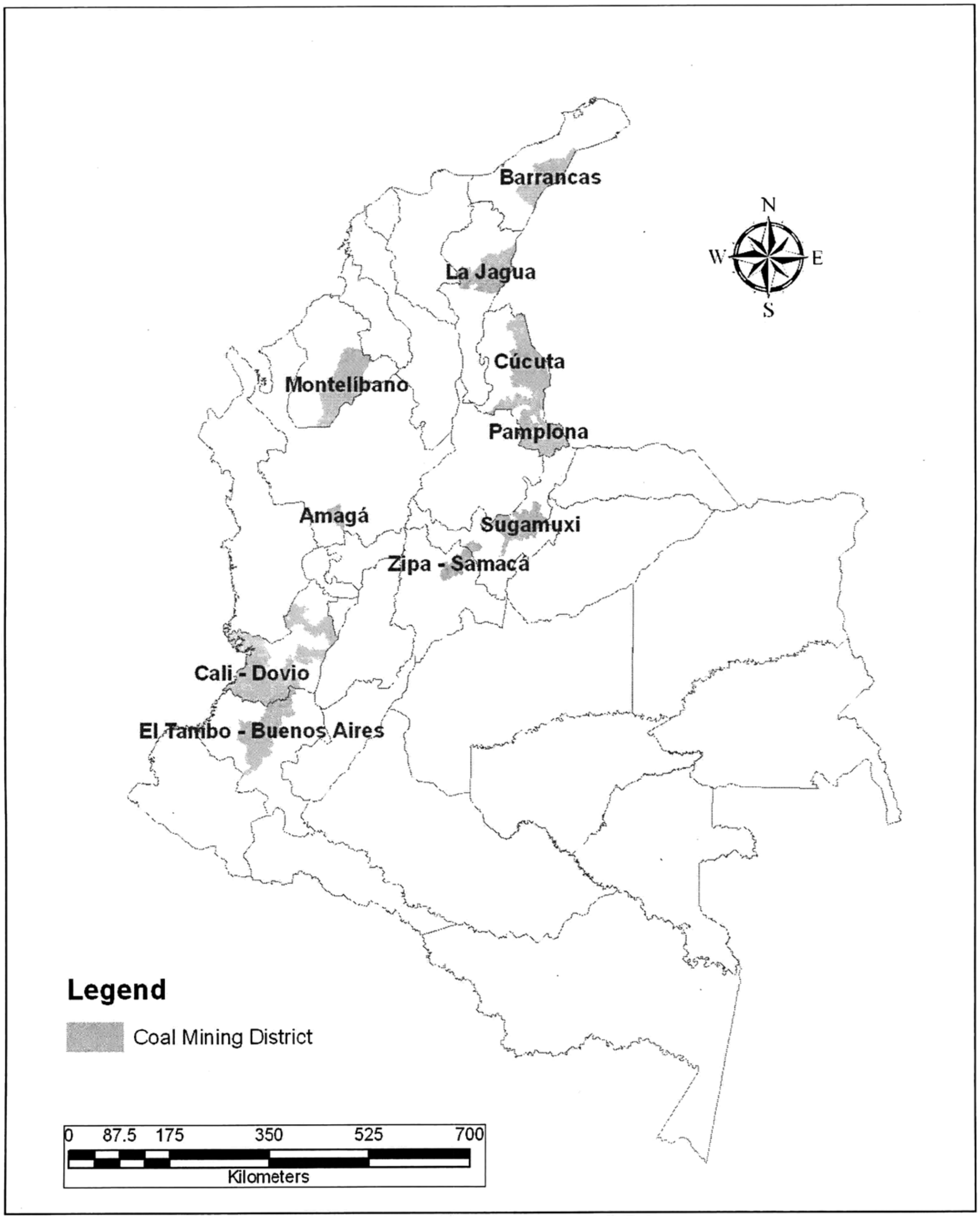
3.4 Mining Districts as a Path for Increasing Competitiveness in Mining

Mining Districts are defined by Minminas (2007) as strategic zones with geographic and geological continuity in which the mining industry is an economic activity of interest and high social impact. I show the coal-mining districts in Colombia in Figure 3.1.

Within these zones, planning and execution of strategies and programs for the sustainable enhancement of the productivity and competitiveness of mining activities are undertaken by public entities, private companies, social organizations, and technical and academic institutions.

Benefits of such territorial division of the stewardship of mineral resources include:

- Construction of high-quality geographic, geological, economic and demographic data bases that allow comprehensive socioeconomic and spatial planning, better management of resources and more effective environmental protection.



Source: IGAC - Colombian GIS Database (2008). Built by Author.

Figure 3.1: Coal-Mining Districts in Colombia.

- Facilitation of the relationship between the State and the community, encouraging bottom-up processes for the formulation of action plans and project oversight.

- Improved resource allocation from the country's budget for project development, technology implementation, social programs, and infrastructure expansion

- Effective integration of mining and processing (value-added) projects to the territorial master development plans of municipalities included in each district. In addition, this structure fosters the linkage of the mining industry´s value chain with other economic activities in the district.

In sum, Mining Districts are territorial divisions for the management of the country's mineral resources intended to optimize planning practices and strategy-making through participatory processes, in order to enhance the mining industry's productivity and competitiveness and to integrate it to the socioeconomic development plans of municipalities that compose each district.

3.5 Framework Combined with the Coal-Mining Competitiveness Agenda

The essential premise of this work is the alignment of conceived alternatives for the development of the coal sector with the strategies designed by the Mining and Energy Ministry, particularly those concerned with the promotion of mining in a sustainable way and the enhancement of the productiveness and competitiveness of the coal industry.

The Mining Districts' structure presents an invaluable opportunity to propose a variety of alternative developments for the coal sector not as isolated processes, independent of the context around them, but as programs that depend on the interaction of the many components of the districts, and that will, by the same token, contribute to the socioeconomic growth of the district. In this spirit, I propose several alternatives for the development of the medium-scale coal industry in coal-mining districts.

3.6 Summary

In this chapter, I presented the Colombian national policies for competitiveness and productivity. In addition, I described how these policies apply for the coal-mining sector and how the Mining Districts model has the potential to advance the competitiveness of the medium-scale coal sector. Further, I indicated the coupling of the framework proposed in this study with the coal-mining competitiveness agenda.

CHAPTER 4

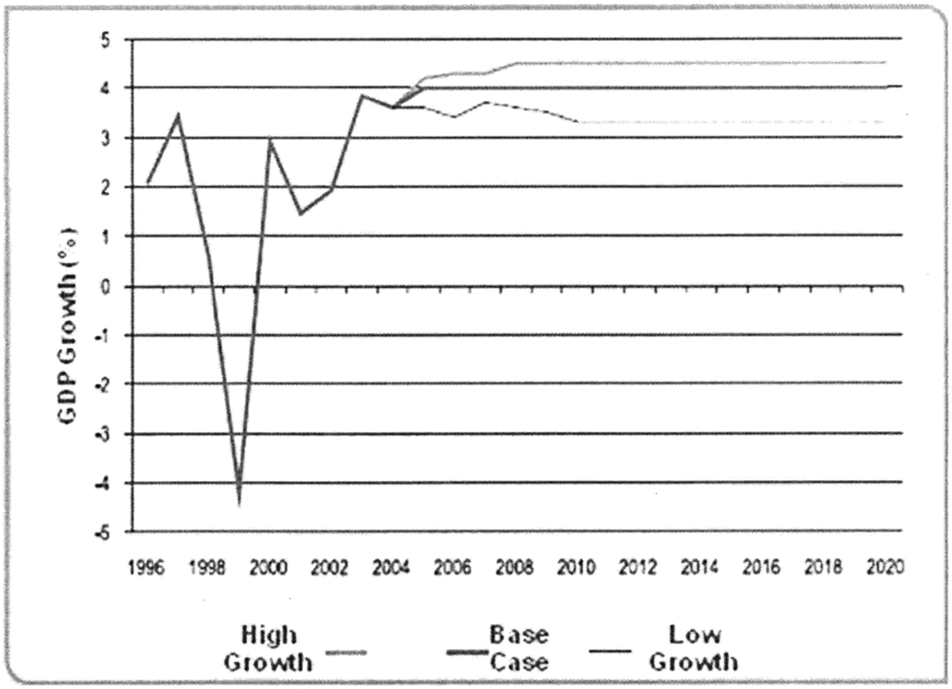
COLOMBIA'S ENERGY SITUATION

For this study, I consider Colombia's energy situation and trends regarding production and consumption of electric power, liquid fuels and natural gas. It is crucial to understand the country's current and long-term energy panorama to see how the proposed coal development alternatives can contribute to satisfy Colombia's growing energy demand.

The Colombian Department of National Statistics (DANE) forecast the annual gross domestic product (GDP) growth of Colombia to 2025. GDP growth estimates by DANE, include a base case, low- and high-growth scenarios as shown in Figure 4.1 (DANE Website: www.dane. gov.co accessed September 2008).

The total annual energy consumption increase in Colombia (i.e., electric power, liquid fuels, and natural gas) indicated in this chapter, was estimated by the Colombian Mining and Energy Planning Unit (UPME) as a function of annual GDP growth.

In addition, the supply of liquid fuels, natural gas, and electric power, included in this chapter, was estimated by the UPME, based on this agency's records of available reserves of oil and gas and the installed capacity of power generation plants until 2025 (Union Temporal CTL 2007 and UPME 2007).



Source: DANE Website: www.dane.gov.co (2008).

Figure 4.1: GDP Growth Forecast by the Colombian National Department of Statistics – DANE.

4.1 Colombia's Energy Outlook

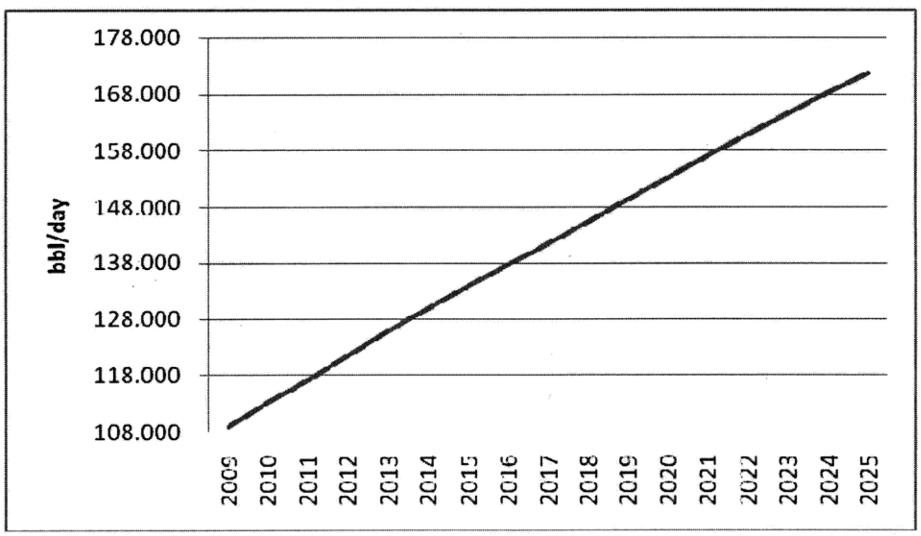
I indicate the energy supply and demand in Colombia, and the balance of energy in order to identify possible shortages of liquid fuels, natural gas, and electric power.

4.1.1 Liquid Fuels

Presently, Colombia's domestic production of diesel fuel and gasoline does not meet the country's entire demand for liquid fuels. Therefore, the country needs to make up for the shortage by importing these products, putting pressures on the country's balance of payments, especially when the international prices of these commodities surge. I present diesel fuel and gasoline supply and demand data below.

Diesel Fuel

As indicated in Figure 4.2, the forecasted demand for diesel fuel increases steadily from 2009 to 2025, due to the estimated expansion of economic activity. As of 2006, the country had a domestic supply of about 75,000 barrels a day (bbl/day) of diesel and a 21,000 bbl/day deficit, which is being compensated with diesel imports. As I show in Table 4.1, by year 2015, Biodiesel plants in the country will supply about 6,300 bbl/day and domestic diesel-fuel production will increase to roughly 100,000 bbl/day. Yet, there will be a 26,000 bbl/day deficit. The sharp growing demand exacerbates the deficit, which by 2025 will be 61,000 bbl/day.



Source: Union Temporal CTL (2007). Built by author.
Note: bbl/day = Barrels per day

Figure 4.2: Diesel-Fuel Demand Forecast in Colombia

Table 4.1 Colombia's Diesel Supply and Demand Forecast Balance, 2015 and 2025

Units: bbl/day

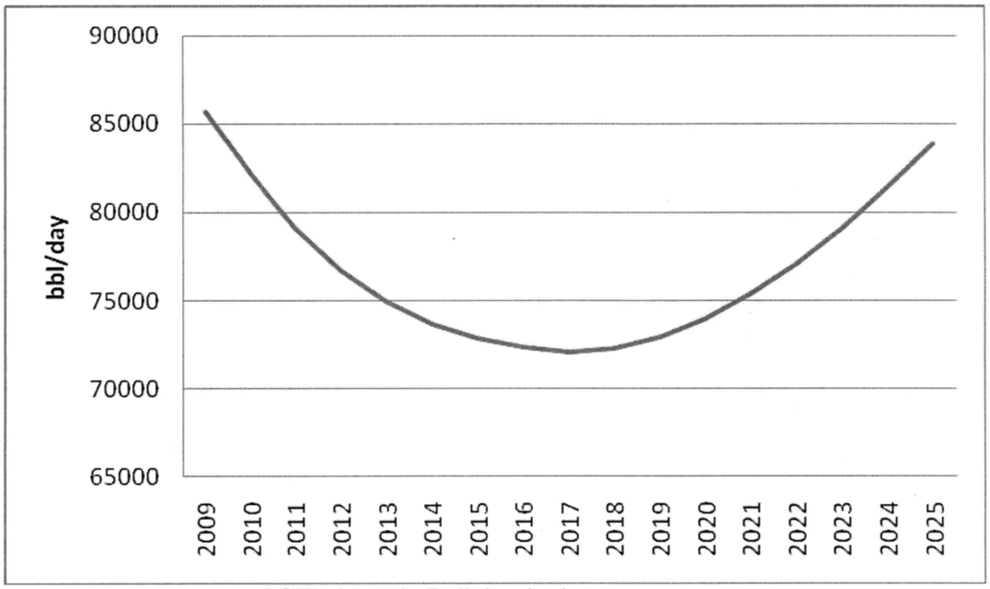
Diesel	**2006**	**2015**	**2025**
National Supply	74,852	100,981	102,464
Biodiesel	-	6,303	8,203
Total Nat'l Supply	74,852	107,284	110,667
Consumption	95,987	133,746	171,753
Deficit	**21,135**	**26,462**	**61,086**

Source: Union Temporal CTL (2007). Calculation: Author

Gasoline

As I show in Figure 4.3, the estimated demand for gasoline decreases, as the existing transportation fleet in the country that used to run on gasoline, is being retrofitted to use diesel fuel. By year 2018, the increase in automobile ownership and use will increase gasoline demand (Union Temporal CTL 2007).

As of 2006 the country had a 15,000 bbl/day deficit of gasoline and, in spite of the decreasing demand, by 2015 the deficit is expected to be about 13,000 bbl/day. The domestic production of gasoline and ethanol is estimated to rise in the 2015 – 2025 period. However, as I indicate in Table 4.2, the gasoline and ethanol production will not suffice to meet the 2025 demand, resulting roughly a 13,000 bbl/day gasoline deficit.



Source: Union Temporal CTL (2007). Built by Author.

Figure 4.3: Colombia's Gasoline Demand Forecast to 2025

Table 4.2: Colombia's Gasoline Supply and Demand Forecast to 2025

Units: bbl/day

Gasoline	2006	2015	2025
National Supply	80,151	53,701	63,376
Ethanol	4,982	6,246	7,347
Total National Supply	85,133	59,947	70,723
Consumption	99,866	72,857	83,861
Deficit	**14,733**	**12,910**	**13,138**

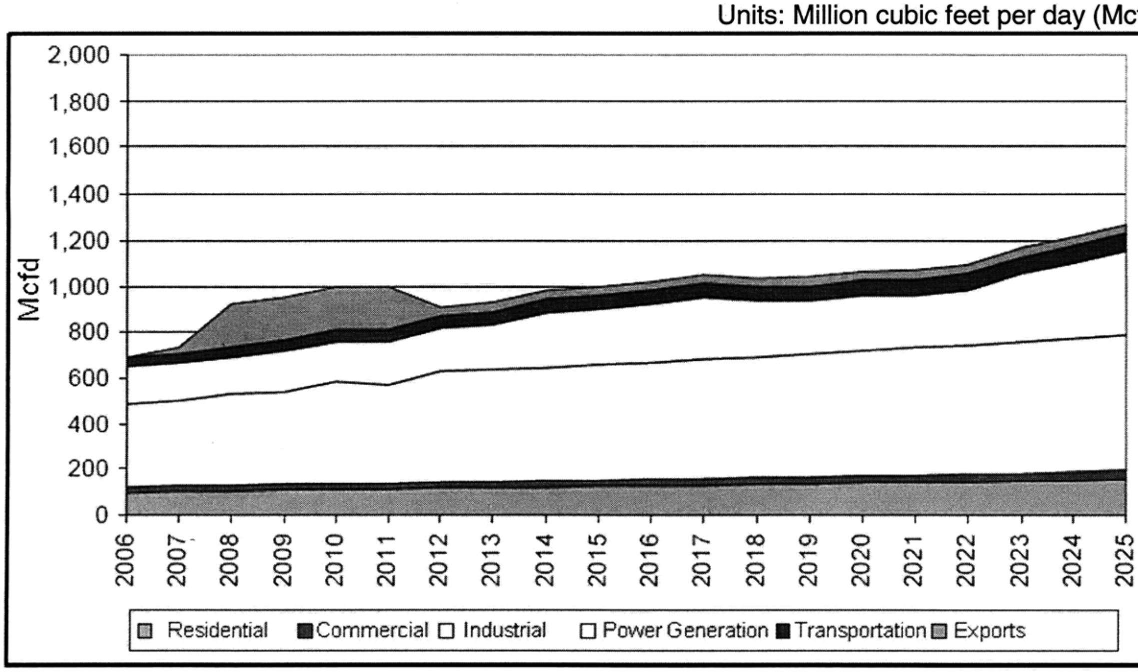
Source: Union Temporal CTL (2007)

4.1.2 Natural Gas

Natural gas is a widely used commodity in Colombia. As I show in Figure 4.4, its demand is rising rapidly, due to economic growth and the increasing use of gas in automobiles and power generation. I show the forecasted natural gas demand in Colombia to 2025 by sectors in Table 4.3, and the expected gas demand share per sector in Table 4.4.

As I indicate in Figure 4.5, the country's reserves of natural gas are shrinking: By 2020, Colombia will only have enough reserves for six more years. This is a critical situation given the country's present and future reliance of the country on gas.

Units: Million cubic feet per day (Mcfd)



Source: UPME (2007)

Figure 4.4: Colombian Natural Gas Demand Forecast.

Table 4.3: Colombia Natural Gas Demand Forecast by Sector

Units: Million Cubic Feet per Day

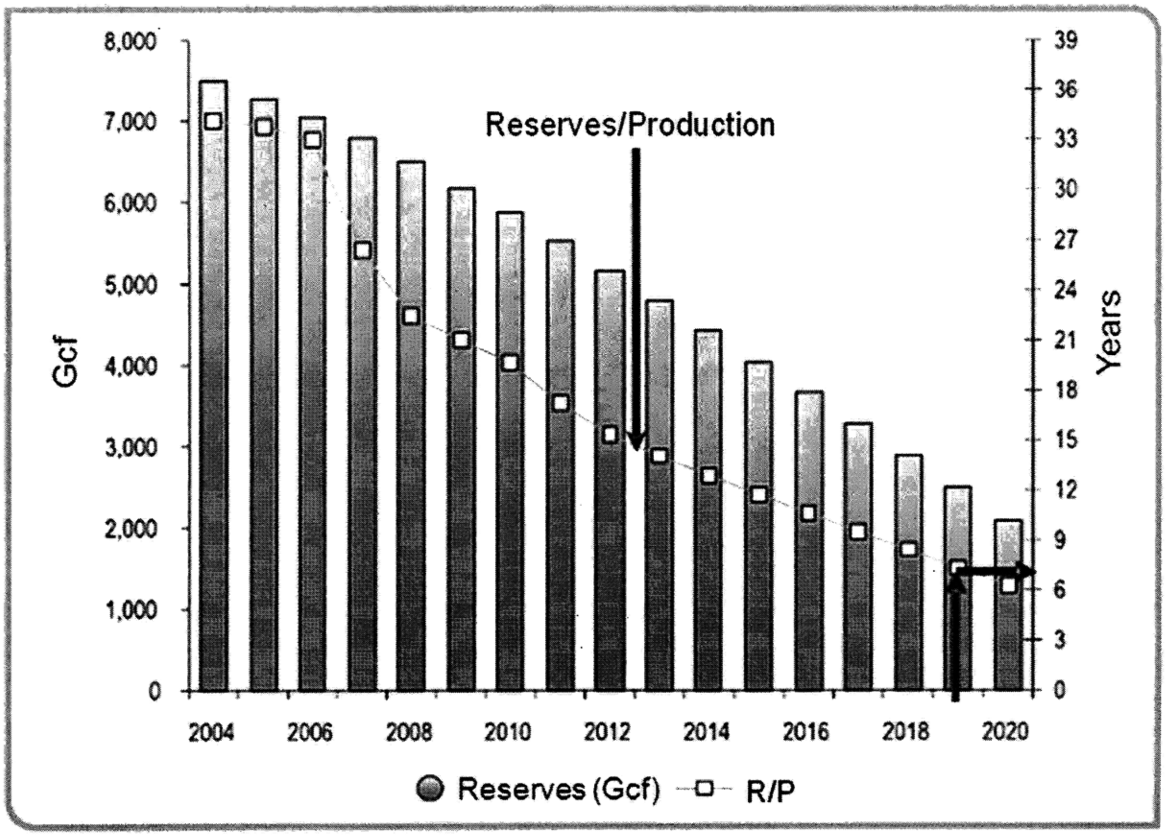
Mcfd	2006	2010	2015	2020	2025
Residential	100.4	111.7	124.9	139.4	156.4
Commercial	20.2	23.4	27.1	31.1	35.4
Industrial	366.2	449.8	506.1	547.1	594.7
Power Generation	162.6	174.7	242.9	241.3	363.6
Transportation	36.4	48.6	57.2	65.4	76.8
Total Consumption	**685.7**	**808.3**	**958.2**	**1024.3**	**1226.9**

Source: UPME (2007)

Table 4.4: Gas Demand Share per Sector Forecast to 2025

Share	2006	2010	2015	2020	2025
Residential	14.6%	13.8%	13.0%	13.6%	12.7%
Commercial	2.9%	2.9%	2.8%	3.0%	2.9%
Industrial	53.4%	55.7%	52.8%	53.4%	48.5%
Power Generation	23.7%	21.6%	25.3%	23.6%	29.6%
Transportation	5.4%	6.0%	6.0%	6.4%	6.3%

Source: UPME (2007)



Source: UPME (2007)
Gcf = Giga cubic feet

Figure 4.5: Gas Reserves and Production Forecast to 2020

4.1.3 Electric Power

Colombia needs to guarantee the supply of electric power to ensure its competitiveness and economic advancement. The country is endowed with vast hydrological resources and most of the energy generated presently is hydropower (UPME 2008b). However, the demand for electric power is growing rapidly and the current installed generation capacity will not suffice. Therefore, new power generation facilities should be implemented to enhance the country´s installed capacity and to provide the required energy for development.

In Table 4.5, I show the electric power demand forecast by UPME to 2014, under different scenarios of economic growth including low, high and base cases.

Table 4.5: Installed Capacity Demand Forecast to 2014 by GDP Growth Scenario

Units: MW

YEAR	HIGH	%	BASE	%	LOW	%
2005	8,786	4.2	8,692	3.1	8,599	2.0
2006	9,095	3.5	8,971	3.2	8,835	2.7
2007	9,396	3.3	9,248	3.1	9,088	2.9
2008	9,738	3.6	9,550	3.3	9,358	3.0
2009	10,098	3.7	9,867	3.3	9,633	2.9
2010	10,455	3.5	10,178	3.2	9,885	2.6
2011	10,826	3.5	10,500	3.2	10,144	2.6
2012	11,226	3.7	10,847	3.3	10,424	2.8
2013	11,650	3.8	11,213	3.4	10,718	2.8
2014	12,085	3.7	11,587	3.3	11,015	2.8

Source: UPME (2008b)
% = Annual growth percentage

In Table 4.6, I include the power output demand forecast by UPME for the same scenarios of economic growth.

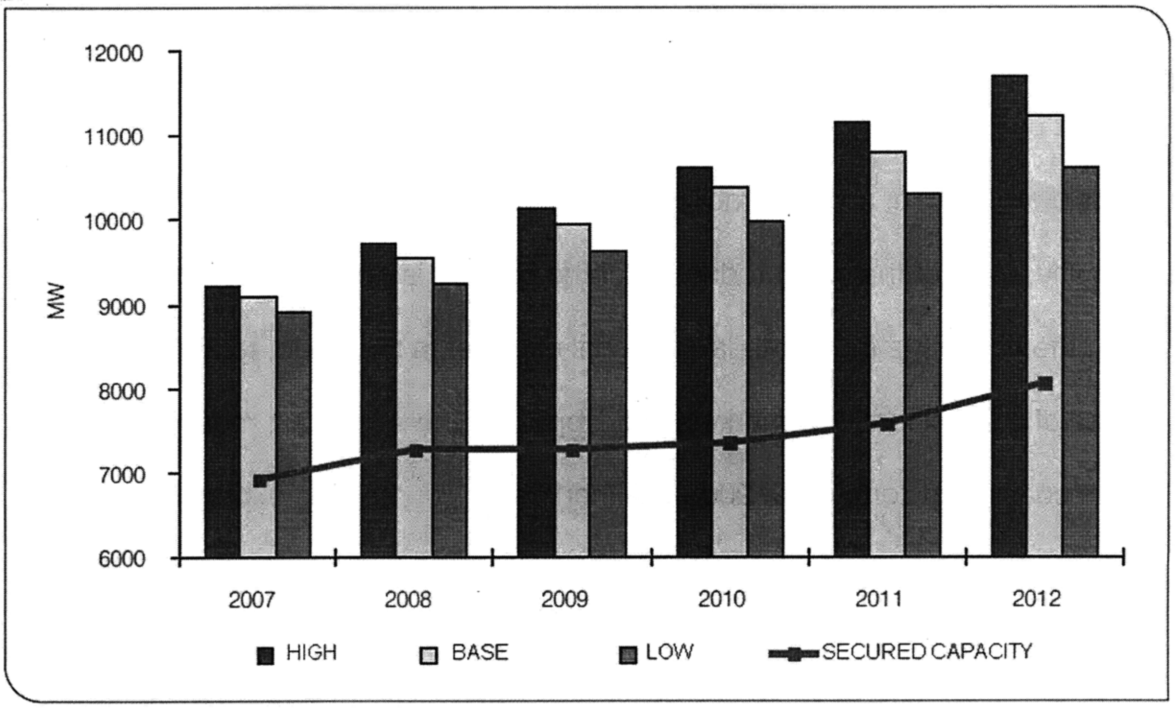
Table 4.6: Total Power Output Demand Forecast to 2014 by GDP Growth Scenario

Units: GWh/yr

YEAR	HIGH	%	BASE	%	LOW	%
2005	48733	3.6	48215	2.5	47697	1.4
2006	50564	3.8	49874	3.4	49117	3.0
2007	52384	3.6	51559	3.4	50668	3.2
2008	54457	4.0	53410	03.6	52337	3.3
2009	56287	3.4	55001	3.0	53696	2.6
2010	58276	3.5	56734	3.2	55100	2.6
2011	60343	3.5	58528	3.2	56543	2.6
2012	62731	4.0	60618	3.6	58258	3.0
2013	64937	3.5	62503	3.1	59742	2.5
2014	67365	3.7	64586	3.3	61396	2.8

Source: UPME (2008b)
% = Annual growth percentage

In Figure 4.6, I describe the projected increase in installed capacity required. The red line represents the power generation capacity that the country has secured by current developments and project procurement. As indicated, the required capacity outstrips the secured capacity.



Source: UPME (2008b).

Figure 4.6: Required Power-Generation Capacity vs. Secured Capacity.2007 to 2012

4.2 Summary

In this chapter, I reviewed the supply and demand energy balance of Colombia in the medium and long term. The country faces pressing shortages of liquid fuels, natural gas, and power-generating capacity. The government needs to implement projects that secure these strategic supplies for competitiveness, and this can be done by implementing projects that transform coal into liquid fuels, gas and electric power, included in the coal development alternatives laid out in this study.

CHAPTER 5

COAL MINING IN COLOMBIA

Several regions in Colombia present large and high-quality reserves of various types of coal including steam coal for power generation, metallurgic or coking coal for coke production, and anthracite for the steel and water-treatment industries. Currently, most of the coal production of the country is dedicated to exports: As of 2007, the country is the fourth largest coal exporter in the world, totaling 67 million tonnes of coal exported to markets in Europe and the Americas, most of it being steam coal in raw form (WCI 2008). Although the country has experienced in the last decade a remarkable surge in the production and exports of steam coal from deposits in the northern region of the country, fields of different types of coal like coking coal and anthracite, products from their transformation like coke, and even steam coal deposits located in the center of the country, have not been developed at a nearly comparable pace, despite having a great potential for expansion and to contribute to the country's socioeconomic growth.

At the same time, medium to low yield coal mines insufficient reductions of environmental adverse impacts due to ineffective environmental controls and oversight, and safety hazards, have raised environmental and health concerns in the country

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5.1 Coal Resources of Colombia

I summarize In Table 5.1 the country's measured and potential coal reserves. The difference between them is the drilling-grid: While measured reserves are obtained by drillings made every 500 meters, potential reserves are inferred by drillings made every 4,500 meters. Both types of resources are expressed in million tonnes.

Table 5.1: Measured and Potential Reserves of Coal in Colombia

Province	Type of Coal	Measured Reserves (MT)	Potential Reserves(MT)
La Guajira	Steam	3,933	4,537
Cesar	Steam	2,035	6,556
Córdoba - Norte de Antioquia	Steam	381	722
Total Northern Region (Atlantic Coast)		6,349	11,815
Norte de Santander	Steam Antracite Coking	120	795
Santander	Steam Antracite Coking	56	464
Boyacá	Steam Antracite Coking	170	1,720
Cundinamarca	Steam Antracite Coking	236	1,482
Antioquia - Antiguo Caldas	Steam	90	475
Valle Cauca - Cauca	Steam	41	242
Total Central Region (Interior)		713	5,178
Total Country		**7,062**	**16,993**

Source: Unión Temporal CTL (2007) citing Ingeominas (2004)

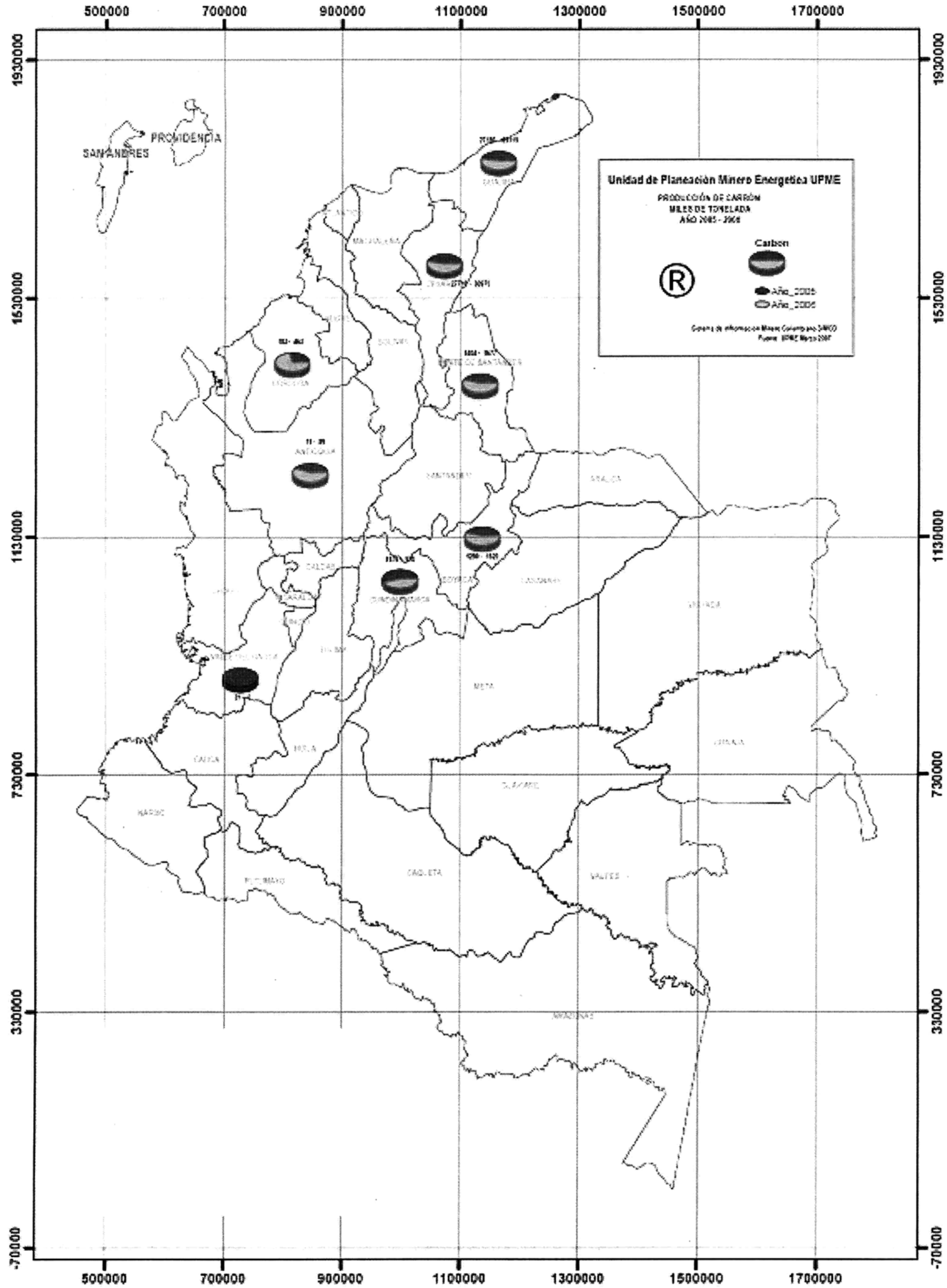
Figure 5.1, shows the coal-producing provinces in Colombia (beige shade), and a production comparison for 2005 and 2006. Guajira, Cesar, and Cordoba Provinces in the north of the country produce steam coal for exports through the ports on the Caribbean.

Table 5.2 shows the distribution percentages by type of coal across the country. These data are crucial for the selection of the mining project and plant location.

Table 5.2 Percentage Distribution of Coal Types in Colombia

PROVINCE	DISTRIBUTION OF COAL TYPES (%)		
	ANTHRACITE	STEAM	METALLURGIC
GUAJIRA	-	100.00	-
CESAR	-	100.00	-
CÓRDOBA - NORTE DE ANTIOQUIA	-	100.00	-
NORTE DE SANTANDER	1.26	54.54	44.20
SANTANDER	18.92	50.00	31.08
BOYACÁ	-	54.57	45.43
CUNDINAMARCA	-	55.04	44.96
ANTIOQUIA - CALDAS	-	100.00	-
VALLE DEL CAUCA - CAUCA	-	100.00	-

Source: Unión Temporal CTL (2007) citing Ingeominas (2004)



Carbon=Coal. Año=Year. Source: UPME (2008a)

Figure 5.1: Coal Mining Provinces and Comparative Productions for Years 2005 and 2006

5.2 Classification of Colombian Coal Operations

Essentially, the coal sector in Colombia can be classified into two main categories:

1. **Large-scale,** high-yield steam-coal projects that are operated by world-class companies, located in Colombia's northern region. The excellent location (proximity to ports), quality, reserves, and suitability for open pit, high-yield mining allowed these operations to increase production rapidly. They have low operation and transportation costs, thorough planning practices, and high levels of mechanization and technology. This category accounts for about 96% of all coal exports from Colombia (UPME 2007). A typical open pit mine is portrayed in Figure 5.2.

Source: Ingeominas (2004)

Figure 5.2: High-yield, Open-Pit Mine in the Cesar Province

2. **Medium-scale**, medium-to-low output coal projects that are operated by national and some foreign companies and local entrepreneurs, located in the Central and Mid-eastern regions of the country (interior). They produce coking coal, anthracite, and transformed products, namely coke; some steam-coal small mining operations supply local markets of the cement industry and coal-fired power generation plants. Because these projects do not have the same competitive advantages and economies of scale as the large-scale operations, transportation and production costs, and lack of continuous and reliable demand, have constrained their development. This sector is the target of my study: When the coal sector is mentioned, it refers to the medium-scale operations unless otherwise specified.

   Even though a specific production threshold to determine the scale of a coal mining project was not found, for this case study, I assume that a production up to 400,000 metric tons per year is medium-scale. This corresponds to the lowest production of a single mining project in the northern region of the country from year 2004 to 2008 (Table A.1).

Source: Ingeominas (2004)

Figure 5.3: Underground Medium-Scale (low yield) Coal Mine

5.3 The Medium-Scale Coal Sector

Some factors affect medium-scale coal operations, such as low technological levels and high cost of transportation, partially due to poor infrastructure. In addition, the mining authorities have not made effective a strategy to implement new activities for the domestic use of coal that enhances the country's productivity and competitiveness.

The results are haphazard development, low efficiency and sustainability, adverse environmental impacts, and low social investment.

However, the medium-scale operations have contributed significantly to the regional and national economy. In the regions where these operations are based, thousands of jobs have been created; royalties and tax revenues have allowed some level of investment in infrastructure and social programs, and the demand for products and services from other industries has had a positive effect on regional output (UPME 2007).

These operations are undoubtedly important for the regional and national economy, as indicated by the National Plan for Mining Development 2007-2010 (UPME 2007). The Colombian Government has stated the need for improving the conditions for their growth, competitiveness, and sustainability, by attempting to overcome location and technological disadvantages and to increase their relevance in the national economy.

Although the government has made clear the objective of fostering sustainable development for the coal sector at the medium-scale, the completed studies are very aspirational and have not helped to develop a profound and detailed understanding of the net (i.e., positive and negative) socioeconomic impacts of these activities. As a result, the Government lacks supportive information to conduct comprehensive planning, leading to shortcomings in achieving this objective.

I propose the planning framework described in Chapter 2, specifying a few key socioeconomic planning tools of analysis for the development of the medium-scale operations including the implementation of value-added activities for coal, that enhance the intermediate demand of products and services, employment and income distribution. This framework complies with the Colombian national agenda for productivity and competitiveness and may help to transform aspirations of coal sector development into strategies for advancement of the sector.

5.4 Coal Uses in Colombia

As mentioned previously, there is an internal market for Steam and Metallurgic coal, whose consumption is described in Table 5.3. Nonetheless, this market is not large enough to justify a greater mining development. Currently, exports are driving medium-scale coal mining developments in the country, particularly of coking coal deposits. This however, does not apply for steam coal.

Table 5.3: Coal Consumption by Sector

Units: Thousand Tonnes

Sector	2000	2001	2002	2003	2004	2005	2006
Power*	1,386	1,446	1,296	1,274	745	970	1,139
Steel Making†	472	493	442	608	417	422	422
Industry	2,092	2,181	1,956	1,752	2,319	2,460	2,466
Residential	109	114	102	101	100	98	98
Total	4,059	4,234	3,796	3,735	2,581	3,950	4,125

*Includes cogeneration. †Includes Coking Facilities and Blast Furnaces.
Source: Unión Temporal CTL (2007)

At current levels, the country has a local consumption of roughly 4 million tonnes. In the next section, I include forecasts for Colombian coal production and exports.

5.5 Production Forecast

I present in Table 5.4 a production forecast, disaggregated by provinces, conducted for the period 2009 to 2025, by the Colombian National Institute of Geology and Mining (Ingeominas).

Table 5.4: Colombian Coal Production Forecast. 2009 to 2025

Units: Million Tonnes

PROVINCE	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
La Guajira	45.0	47.4	47.9	48.4	48.8	49.6	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8
Cesar	48.0	50.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5
Córdoba	0.2	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Cundinamarca	1.5	1.7	1.7	1.7	1.7	1.7	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Boyacá	1.8	2.0	2.0	2.0	2.0	2.0	2.0	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
Norte de Santander	2.8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Antioquia	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Valle del Cauca	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Santander	1.0	1.5	2.0	2.8	3.7	5.0	6.7	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1
TOTAL	**101.5**	**107.7**	**124.9**	**126.1**	**127.6**	**129.4**	**131.6**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**	**134.0**

Source: Unión Temporal CTL (2007) citing Ingeominas (2004)

5.6 Exports Forecast

In Table 5.5, I show exports forecast, disaggregated by provinces, for the period 2009 to 2025.

Table 5.5: Colombian Coal Exports Forecast. 2009-2025

Units: Million Tonnes

PROVINCE	2009	2010	2011	2012	2013	2014	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
La Guajira	45.0	47.4	47.9	48.4	48.8	49.3	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8	49.8
Cesar	48.0	50.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5
Cundinamarca	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Boyacá	1.3	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Norte de Santander	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Antioquia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Valle del Cauca	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Córdoba Montelíbano	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	**96.7**	**102.0**	**118.5**	**119.0**	**119.4**	**119.9**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**	**120.4**

Source: Unión Temporal CTL (2007) citing Ingeominas (2004)

As compared in the production and exports charts, La Guajira and Cesar are entirely oriented to exports.

Based on the measured and potential reserves, the types of coal and the production forecast, the most suitable provinces to develop large-scale coal mining and transformation projects in the interior of the country are Santander, Boyacá, Cundinamarca, Norte de Santander, and the region composed by Cordoba Province and the North of the Antioquia Province. In the next section, I describe the coal qualities for these regions.

5.7 Coal Qualities

In Table 5.6, I include the results of proximate analyses and characterizations obtained for the regions suitable for high-yield coal-mining development

The qualities observed in Table 5.6, show high-quality coal in areas like Norte de Santander, Córdoba and Norte de Antioquia, Boyacá, and Cundinamarca. In parameters like sulphur (S), and ashes, Colombian coal performs better than the design coal type, Illinois #6, shown in Table 6.1, making it suitable for the coal development alternatives discussed in Chapter 6.

Quality details are provided for coal resources across the country in Tables A.1 and A.2.

Table 5.6: Medium-Scale Coal Qualities

Province	Area	Proximate Analysis (%)							COAL TYPE
		Base[1]	Moisture	Ash	VM	FC	S	CV	
Córdoba - Norte de Antioquia	Alto San Jorge	BCA	14.49	9.24	37.55	38.73	1.31	9,280	T
Norte de Santander	Salazar	ROM	3.76	9.46	36.81	49.96	0.62	12,762	T.M.
	Tasajero	ROM	2.84	10.17	34.82	52.18	0.85	13,326	T.M.
	Zulia	ROM	3.36	11.90	35.29	49.45	1.27	12,967	M
	Catatumbo	BCA	4.31	8.64	39.17	47.88	0.95	12,316	T
Santander	San Luis								
	- Térmicos	BAC	1.18	18.72	30.48	49.62	2.01	12,284	T
	- Metalúrgicos	BAC	1.18	10.09	29.05	59.67	2.15	13,893	M
	Páramo del Almorzadero	BCA	5.18	4.71	14.23	75.88	0.75	12,889	A.T.
Boyacá	Checua	ROM	3.56	10.00	25.19	61.25	0.80	13,439	T.M.
	Albarracín	ROM	4.69	12.18	33.71	49.42	1.07	12,420	T
	Sogamoso - Jericó	ROM	4.29	9.57	30.19	55.96	1.23	13,099	T.M.
Cundinamarca	Lenguazaque	ROM	4.67	10.62	33.85	50.86	1.06	12,718	T.M.
	Suesca	ROM	3.92	10.43	33.53	52.12	0.69	12,738	T

Source: Union Temporal CTL (2007) – Modified: Author
Notes: [1] Indicates source of sample: ROM= Run of Mine; BCA = Different from the mine.
T=Thermal (Steam). M=Metallurgic (Coking). A=Anthracite. VM=Volatile Matter. FC=Fixed Carbon.
S=Sulphur. CV=Calorific Value.

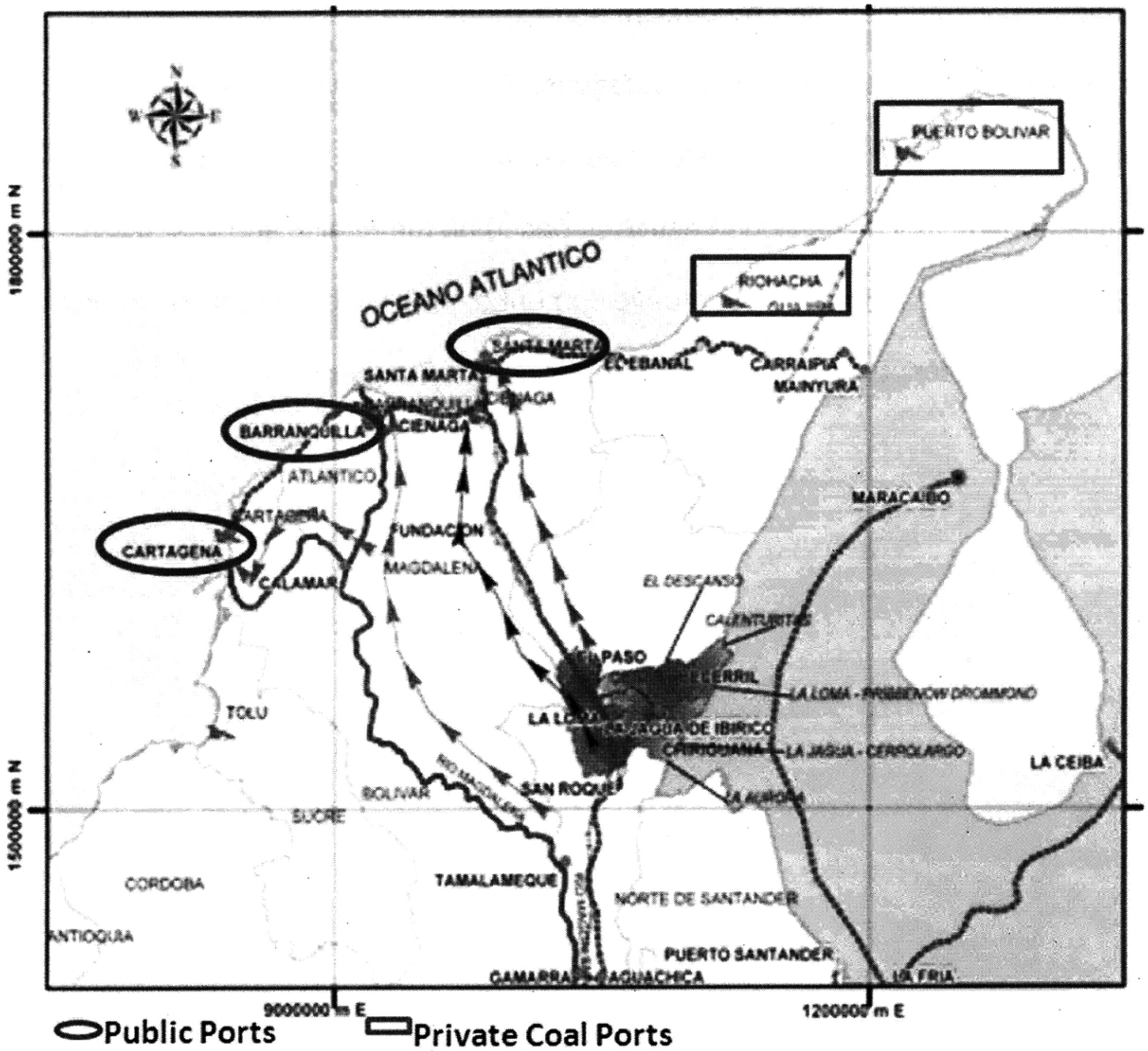
5.8 Transportation Cost

Trucking transportation cost from the coal mining areas to the main ports in Colombia is described in Table 5.8. In Figure 5.4, I illustrate the coal port locations in the northern region of Colombia and their ownership.

Table 5.8: Coal Trucking Cost for Exports

Route	Distance (km)	USD/T	USD/T-km
La Jagua - S.Marta	285	7.56	0.027
La Jagua - Barranquilla	312	8.08	0.026
Cerrejón - Santa Marta	187	5.72	0.031
Lenguazaque - Buenaventura	586	17.78	0.030
Lenguazaque - Pto. Slagar - Barranquilla	1,091	29.95	0.027
Troncal del Carbón (Rough Road)	72	4.06	0.056
Cúcuta - Barranquilla	667	18.68	0.028
Cúcuta - La Ceiba (Venezuela)	324	8.64	0.027
Cúcuta - Maracaibo (Venezuela)	417	10.13	0.024

Source: UPME (2005)



Source: UPME (2005)

Figure 5.4: Location and Ownership of Coal Ports in Northern Colombia

5.9 Summary

In this chapter, I provide an overview of the Colombian coal sector, including the different scales of mining operations in the country and how they have developed. I described the advantages of the large-scale coal sector and the challenges of the medium-scale coal sector. Further, I discussed Colombia's coal endowment, the national consumption, and production and exports forecasts. I also illustrate transportation costs and coal port locations. Finally, I indicate how the proposed framework in Chapter 2, may help advance the medium-scale coal sector by the implementation of value-added activities based on the quality and vast reserves of areas with great potential for the development of high-yield coal-mining operations. A detailed description of that framework follows in Chapter 6.

CHAPTER 6

MEDIUM-SCALE COAL-DEVELOPMENT ALTERNATIVES IN COLOMBIA

Thus far, I have discussed the policy for improving productivity and competitiveness in Colombia, the country's energy situation and requirements for that purpose, and the availability and advantages of coal mining in the country. To enhance the country's competitiveness by using its own abundant resources and quality, I propose the implementation of alternative developments of medium-scale coal fields in the interior of the country, whose suitability is difficult for exports, due to the high cost of the available means of transportation (i.e., truck), and lack of more efficient transportation alternatives, like railroad or river navigation.

I propose the development alternatives of medium-scale coal fields, relying on constant and long-term consumption from processes that add value to coal for the production of power and fuels. Colombia needs energy for its development, and its sourcing is a challenge in the medium and long run.

In addition, these alternatives should be large enough in scale so as to reach levels where planning and mining of coal fields, processing of coal, and distribution of final goods are cost effective, and returns are attractive to the public or private investor for the kind of investments required. Furthermore, the projects should meet the country's growing demand for commodities, the environmental regulations, which should be ecologically sound, and produce a significantly positive economic impact on the economy.

Freudenthal (1974), proposes several projects in Wyoming State (United States), in an evaluation from the water requirements and environmental impacts standpoint for the use of steam coal in the production of liquid fuels, gas, and electric power. According to the needs of Colombia and opportunities in the coal sector, the implementation in the country of these alternatives is plausible. Therefore, the set of alternatives for the development of steam coal deposits include:

- Intensification of Coal-Based Power Generation
- Coal Liquefaction
- Coal Gasification

Coking coal is also a target for development. Presently, most of the coking coal is being exported from Colombia, as its international price allows producers to cover the cost of trucking and handling all the way to the ports. Nonetheless, international prices are cyclical, which may cause setbacks in the development of coking-coal projects when prices are low. Furthermore, as coking coal is the raw material for the production of coke, which at the same time is one of the main inputs for steel, a potential to enhance the value chain of coking coal within Colombia becomes possible.

Consequently, I present a set of alternatives for the development of coking-coal deposits. These are ongoing activities in Colombia that I compare using the same framework with the purpose of identifying which alternative would bring about the most benefits to the country from the economic point of view:

- Steel Production Intensification
- Coking-Coal Export Intensification

Further, I provide a technical and economic overview of the alternatives for steam coal and coking coal in Sections 6.2 and 6.3.

6.1 Acronyms and Abbreviations

In this section, I include a list of the acronyms and abbreviations used, for easier interpretation.

ASU	Air Separation Unit
bbl	Barrel
bbl/day	Barrels per Day
BGL	British Gas Lurgi
Btu	British Thermal Unit
CO_2	Carbon Dioxide
COP	Colombian Pesos
CTL	Coal to Liquids
CV	Calorific Value
ExRate	Exchange Rate
FC	Fixed Carbon
FGD	Flue gas desulfurization
FOB	Free on Board
F-T	Fisher-Tropsch Process
GW	Gigawatts
GDP	Gross Domestic Product
GWh	Gigawatt-hour
h	Hour
HHV	High Heating Value
IGCC	Integrated Gasification Combined Cycle
kg	Kilogram
kW	Kilowatts
kWh	Kilowatt-hour

lb	Pounds
LHV	Low Heating Value
m	Meter
m^3	Cubic meter
MCOP	Million Colombian Pesos
min	Minute
MMBtu	Million Btu
t	Metric Ton
Mt	Million Tonnes
MUSD	Million United States Dollars
MW	Megawatts
MWh	Megawatt-hour
psia	Pounds per square inch absolute
RDS	Research Development Solutions
scf	Standard cubic feet
scfa	Standard cubic feet absolute
SCR	Selective Catalytic Reduction
St	Total Suphur
TPC	Total Plant Capital
U.S. DOE	U.S. Department of Energy
USD	United States Dollars
VM	Volatile Matter
wt%	Weight Percent
yr	Year

6.2 Steam Coal Development Alternatives

For all the alternatives in the U.S. Department of Energy (DOE) baseline studies, the chemical characteristics of the design-type coal, Illinois #6 Coal, are shown in Table 6.1.

Table 6.1: Design Illinois #6 Coal Characteristics

Proximate Analysis (As Recd), wt %	
Moisture	6.97
Ash	11.76
Volatile	32.49
Fixed Carbon	48.78
	100.00

HHV, Btu/lb (As Recd)	11,714
LHV, Btu/lb (As Recd)	11,313

Ultimate Analysis (As-Received), wt %	
Carbon	64.98
Hydrogen	4.36
Nitrogen	1.28
Chlorine	0.09
Oxygen	7.41
Ash	11.76
Sulfur	3.15
Moisture	6.97
	100.00

Source: U.S. DOE (2007a)

The quality of Colombian medium-scale coal deposits, shown in Table 5.6, is superior to that of the design coal-type Illinois #6. The Colombian coal performs better in parameters like Calorific Value, and content of ash and sulphur. Therefore, the Colombian medium-scale coal is suitable for the development alternatives proposed, and may improve processing efficiency and environmental performance, including lower sulphur emissions.

I modify all the alternatives for a coal production target of 4 million tonnes (current national coal consumption), assuming constant returns to scale.

Labor costs may vary when adjusted to the Colombian case. However, I assume engineering know-how to be sourced from the United States. Therefore, labor and engineering costs will be the same for the set up in Colombia, and any positive labor-cost difference between the United States and Colombia will be kept as a project contingency.

6.2.1 Intensification of Coal-Based Power Generation

The capacity of a country to generate power is fundamental for its competitiveness and economic prosperity. This consideration, justifies a project for securing the power-generating capacity of the country.

In this section, I include a performance and cost overview of a coal-fired reference power plant from a U.S. DOE comprehensive study titled *Cost and Performance Baseline for Fossil Energy Plants*, an analysis for a variety of fossil energy plants in the United States.

Reference Coal-fired Power Plant Overview

I modify this overview from U.S. DOE (2007a):

From the U.S. DOE (2007a), I select for this case study the Pulverized Coal-Supercritical Unit. This type of plant is suitable to illustrate the impact of expanding the country's generating capacity through a new plant that has similar characteristics as the country's conventional coal-fired power plants, having basically the same input-output linkages. Carbon capture is the chief innovation for the mitigation of environmental impacts.

The description below follows the block-flow diagram in Figure B.1, and stream numbers reference the same Figure. Table B.1 provides the Balance of Plant assumptions.

This plant produces the power required for its operation and has a net output of 546 MW at a plant efficiency of 27.2% (HHV basis), assuming a capacity factor of 85%. Coal (stream 6) and primary air (stream 4) are introduced into the boiler through the wall-fired burners. Additional combustion air, including the overfire air, is provided by the forced draft fans (stream 2). The boiler operates at a slight negative pressure so that air leakage is into the boiler, and the infiltration air is accounted for in stream 5.

Flue gas exits the boiler through the SCR reactor (stream 8) and is cooled to 177°C (350°F) in the combustion air preheater (not shown) before passing through a fabric filter for particulate removal (stream 10). A fan increases the flue gas temperature to 188°C (370°F) and provides the motive force for the flue gas (stream 11) to pass through the FGD unit. Inputs and outputs include makeup water (stream 13), oxidation air (stream 14), limestone slurry (stream 12) and product gypsum (stream 15). The clean, saturated flue gas exiting the FGD unit (stream 16) passes to the plant stack and is discharged to the atmosphere.

I summarize the overall plant performance in Table B.2, which includes auxiliary power requirements. The environmental performance of the plant and the water balance, are presented in Tables B.3 and B.4, respectively. Further technical information is available in U.S. DOE (2007a).

Capital Cost

The capital cost considered for this case-study is based on U.S. DOE (2007a). As mentioned in that publication, capital costs were estimated by WorleyParsons based on simulation results and through a combination of existing vendor quotes, scaled estimates from previous design/build projects, or a combination of the two.

A summary of the capital and performance cost of the Pulverized Coal reference plant described in U.S. DOE (2007a), including the criteria relevant for this case study, is presented in Table 6.2. Further detail of the total capital cost for the base case is included in Table B.5.

Table 6.2 Cost and Performance Parameters of the U.S. DOE Pulverized Coal Reference Power Plant

Supercritical Unit - 550 Mw	
TPC (2006 MUSD)	1,724
Output (MW)	546
Coal Consumption (t/h)	267
Power to Coal Ratio (MWh/t):	2.05
Capital (USD/kW)	3,157
CO_2 Emmisions (Kg/MWh)	115
Total CO_2 Emmisions (kg/h)	62,790
Raw Water Consumption(m^3/min)	39.5

TPC = Total Plant Cost
Source: DOE (2007a). Calculations: Author.

The Total Plant Cost reflects the overnight construction capital. It includes a 15% project contingency, 10% owner cost, and excludes financial costs. Figures are in 2006 U.S. Dollars.

The plant scale described above has an installed capacity of 550 MW and a consumption of 267 MT/hr or roughly, 2.34 million tonnes per year. For this case study, the coal field development is targeted to have a production of 4 million tonnes per year. Projects must equal coal consumption to that level and therefore capital, output, and performance ought to be adjusted to the target coal consumption of 4 Mt. I made the adjustments presented in Table 6.3 assuming constant returns to scale.

Table 6.3: Cost and Performance Parameters of the Case Study Pulverized Coal Power Plant

Pulverized Coal Supercritical Process - 940 MW	
Production (MWh):	935
Coal Consumption (T/h):	457
TPC (2006 MUSD)	2,952
TPC (2006 **MCOP** ExRate = 2361,14)	6,969,918
CO_2 Emmisions (kg/MWh)	115
Total CO2 Emmisions (kg/h)	107,525
Raw Water Consumption(m3/min)	67.64

TPC = Total Plant Cost. MCOP = Million Colombian Pesos.
Exchage Rate = 2361,14
Source: Author's Calculations..

The total plant cost is also indicated in million Colombian Pesos (MCOP), calculated at the 2006 average exchange rate from Nationmaster (2008).

6.2.2 Coal Liquefaction

Colombia is facing a shortage of oil and liquid fuels (gasoline and diesel) in the medium and long term, as I described in Chapter 4. Overtime, the ratio of daily production to reserves will decrease sharply, forcing the importation of liquid fuels whose price and source changes every day.

A technology to convert coal into liquid fuels is readily available and has been used since WWII. Nowadays countries like South Africa rely heavily on Coal to Liquids (CTL) plants for their liquid fuels supply. In that country, CTL plants provide about 28% of the country's total fuel demands (Unión Temporal CTL 2007).

In the case of Colombia, CTL plants would represent a very suitable alternative for the production of liquid fuels, based on the country's great coal potential described in Chapter 5, making up for fuel shortages and relieving the fuel import pressures on the economy.

In this section, I present an overview of a Coal to Liquids (CTL) reference plant based on a comprehensive study conducted by the U.S. DOE in year 2007, titled *Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility*. The general description, capital cost, and performance relevant for this case study are included below, and more detailed cost and technical information are included in the Appendix.

CTL Reference Facility Overview

I modified this overview based on U.S. DOE (2007b):

U.S. DOE (2007b) examines the technical and economic feasibility of a commercial 50,000 barrel per day (bbl/day) reference CTL facility. The facility employs gasification and Fischer-Tropsch (F-T) technology to produce commercial-grade diesel and naphtha liquids from medium-sulfur bituminous coal defined as Illinois #6 coal, described in Table 6.1. A conceptual design development, process analysis, component descriptions, capital and operating cost estimates, and financial analysis, are available in U.S. DOE (2007b).

The plant design described in U.S. DOE (2007b), incorporates coal-gasification technology and an F-T reactor system using an iron-based catalyst. The concept includes a cluster of four gasification plants, each containing two gasifier trains for a total of eight gasifier trains. Clean syngas from the gasification plants is pooled and ducted to a central CTL plant. The CTL plant contains F-T reactors, hydrotreating units and hydrocracking units capable of producing 27,819 bbl/day of commercial-grade diesel liquid and 22,173 bbl/day of naphtha liquids, which could be shipped to a refinery for further upgrading into commercial-grade gasoline, or for use as a feedstock for the chemicals industry.

The CTL plant also generates electric power, both for internal use and for export to the grid. The plant design includes equipment to separate and compress carbon dioxide to 2,200 psia for injection into a pipeline. Subsequent off-site use and/or sequestration of carbon dioxide are not considered in the U.S. DOE (2007b). Figure B.2 represents the block-flow diagram of the CTL process. Plant performance summary and the balance of plant are shown in Tables B.6 and B.7, respectively.

Capital Cost

The capital cost considered for this case-study is based on U.S. DOE (2007b). As indicated there, total plant capital cost estimates are based on costs developed independently for prior Integrated Gasification Combined Cycle (IGCC) power plants and F-T liquids facilities adjusted for the specific design criteria of this reference plant. Costs are based on a combination of adjusted vendor-furnished cost data and the Research Development Solutions (RDS) cost estimating database.

The capital costs of the reference CTL plant at the Total Plant Cost level, include equipment, materials, labor, indirect construction costs, engineering, and contingencies. The capital cost, specifically referred to as Total Plant Cost (TPC) for the plant, was estimated by the U.S. DOE for the categories consisting of bare erected cost, engineering and home office overheads, and contingencies. The TPC level of capital cost is the “overnight construction” estimate.

In a financial analysis performed in U.S. DOE (2007b), it is concluded that the project will be feasible with oil prices above 37 USD/bbl, getting a return on investments of 19% and an investment recovery period of 5 years.

The Capital Cost and Performance criteria of U.S. DOE (2007b) are summarized in Table 6.4. Further capital cost details are described in Table B.8.

Table 6.4: Coal to Liquids Reference Plant Capital Cost Summary

Coal Liquefaction Plant - 50,000 bbl/day	
TPC (2006 MUSD)	4,070
Coal Consumption (t/day)	24,533
Liquid Fuel to Coal Ratio (bbl/t)	2.04
MMBtu/MT of Coal	12.23
Capital (USD/bbl-day)	81,397
CO_2 Emmisions* (kg/h)	56,390
Raw Water Consumption (m^3/min)	5.7

*Based on 96% Daily carbon dioxide (CO_2) capture included in the performance summary.
Source: DOE 2007b. Calculations: Author

For the above description, TPC is in 2006 U.S. Dollars, includes 10% owner cost, a 26% project contingency, and precludes the financial cost.

Although these estimates provide insights about the capital and performance of a CTL plant of 50,000 bbl/day, the reference plant coal consumption is more than twice the planned production of the coal development. Therefore, I downscale the plant statistics to match the target coal production of 4 Mt/yr. Assuming constant returns to scale, I adjusted the TPC, coal consumption, and plant performance, with the results shown in Table 6.5.

Table 6.5: Case-study Coal to Liquids Plant Capital and Performance Summary

Coal Liquefaction Plant - 22.300 bbl/day	
Production: (bbl/day)	22,335
Coal Consumption (t/day)	10,959
TPC (2006 MUSD)	1,818
TPC (2006 **MCOP** ExRate = 2361,14)	4,292,565
CO_2 Emmisions (kg/h)	25,189
Raw Water Consumption (m3/min)	2.5

TPC = Total Plant Cost. MCOP = Million Colombian Pesos.
Exchange Rate = 2361,14
Source: Author's Calculations.

The Total Plant Cost is also indicated in Millions of Colombian Pesos (MCOP), calculated at the 2006 average exchange rate from Nationmaster (2008)..

6.2.3 Coal Gasification

Colombia´s natural gas situation is similar to that of liquid fuels: demand rises every year due to continuous expansion of the national industry, gross domestic product (GDP), and exports, while reserves shrink and new gas fields discovery does not suffice for making up the long-term demand.

Also, in this case, there are readily available technologies to convert coal into gas. Coal-Gasification technologies have been developed extensively in the last decades in many countries, including the United States, to secure gas supply using the current and most abundant fossil fuel available: coal.

In this section, I present a technical and economic overview of a reference coal-gasification plant. The plant type is described in a comprehensive study performed by the U.S. DOE in year 2007 titled *Industrial Size Gasification for Syngas, Substitute Natural Gas and Power Production*. I extracted general technical and processing descriptions from DOE (2007c) as follows.

Coal-Gasification Reference Plant Overview

I modified this overview based upon U.S. DOE (2007c)

U.S. DOE (2007c) is baseline study performed to evaluate the technical and economic viability of a coal-derived synthesis gas (syngas) facility. The U.S. DOE's study includes the development, conceptual design, and economic feasibility for a coal-derived syngas reference plant, based on the British Gas Lurgi (BGL) 1,000 gasifier being marketed in North America by Allied Syngas Corporation, with a nominal gasifier capacity of approximately 1,000 million Btu/h (1 MMBtu/h) of synthesis gas.

The Reference Syngas Production Plant produces approximately 158,700 lb/h (952 MMBtu/h) of cleaned syngas with a higher heating value of about 6,290 Btu/lb (337 Btu/scfa) and lower heating value of about 5,894 Btu/lb (316 Btu/scfa), form approximately 1,118 MMBtu/hr of Illinois #6 coal. The net plant thermal efficiency is about 74.7%.

This plant consumes about 1,040 T/day of Illinois #6 coal type, described in Table 6.1. Internal systems use about 7,300 lb/hr of the syngas for steam generation, resulting in a net syngas product of about 151,400 lb/hr. A sketch showing the major processes comprising the system is presented in Figure B.3.

Capital Cost

As noted in U.S. DOE (2007c), the approach to capital-cost development is a combination of WorleyParsons' estimates of selected specific major systems to supplement the costs from an in-house BGL gasifier cost model that develops capital costs for an entire IGCC power plant. The format includes separate evaluation of major systems and sub-systems for the entire plant. These costs are determined with several levels of complexity depending on the specific system being estimated. The capital cost at the level of Total Field Cost includes equipment, materials, and installation labor. The resulting capital cost is provided as an estimate, recognizing each cost account for the plant. A summary of the reference plant's performance is included in Table B.9, and the main components of the capital cost are described in Table B.10.

I present the performance and cost criteria of the reference plant in Table 6.6.

Table 6.6: Coal-Gasification Reference Plant Cost and Performance Summary

Coal Gasification Plant - 1,650 t/day (22,848 MMBtu/day)	
TPC (2005 MUSD)	161
Syngas Production (t/day)	1,652
Coal Consumption (t/day):	1,041
Gas to Coal Ratio (MMBtu/ t of coal)	21.95
Capital ($/t of gas-day)	97,755
CO_2 Emmisions (kg/MMBtu)	102.27
Raw Water Consumption(m^3/min)	0.89

TPC = Total Plant Cost.
Source: DOE (2007b). Unit Conversions: Author.

The TPC indicated above is in 2005 U.S. Dollars, includes 10% owner's cost, 26% project contingency, and does not include the financial cost.

This reference plant has a much lower coal-consumption level than the targeted production of the proposed coal development. In order to have a gas production consistent with the normalized coal consumption of four Mt/yr, it is necessary to upscale the reference plant. Additionally, U.S. DOE (2007c) does not consider a carbon-capture unit for the reference syngas plant. I solve this by assuming 15% of

TPC as the Carbon-Capture unit cost. I also assumed CO_2 emissions for this case-study gasification plant to be the same as the coal-liquefaction case-study plant, described in the previous section.

Assuming constant returns to scale, I adjusted the total plant cost, coal consumption, and plant performance, with the results described in Table 6.7.

Table 6.7: Case-study Coal-Gasification Plant Cost and Performance Summary

Coal Gasification Plant - 17,400 T/day (240,943 MMBtu/day)	
Production (t of gas/day)	17,390
Coal Supply (t/day):	10,959
TPC (2005 MUSD)	1,700
TPC (2006 MUSD – No CO_2 Capture)	1,754
Carbon Capture Unit (2006 MUSD)*	263
TPC (2006 MUSD With CO_2 Capture)	2,018
TPC (2006 **MCOP** ExRate = 2361,14)	4,763,655
Total CO_2 Emissions (kg/h)	25,189
Raw Water Consumption(m^3/min)	9.39

TPC = Total Plant Cost. MUSD = Million U.S. Dollars.
MCOP = Million Colombian Pesos.
* 15% of 2006 TPC.
Source: Author's Calculations.

6.3 Economic Evaluation of Steam Coal Development Alternatives

Following the framework described in Chapter 2, I performed an assessment of each of the previous alternatives for the coal industry development from the macroeconomic and environmental points of view.

I used input-output (IO) analysis to determine the "ripple effect" of each investment alternative on the economy. Using this analytical tool, I forecast total output of all the sectors in the economy and income due to the investment demand of any of those alternatives. In addition, I obtained the coal industry output specifically for each case.

To conduct this analysis, I use the 2006 Colombian national account matrix at current prices, which shows the transactions among sectors in the country, the final demand, and value-added account for that year. This table is provided by the Colombian National Department of Statistics (DANE) and included 59 sectors originally. To simplify the analysis, I aggregated the table to 28 sectors by collapsing common subsectors. The original input-output (IO) matrix is available at the DANE webpage (www.dane.gov.co/index.php?option=com_ content&task= category& sectionid=33&id=57&Itemid=239, accessed in June 2008), and the modified IO matrix is shown in Table B.11.

6.3.1 Model Overview

As I intend to forecast the income for the work force in the form of wages and salaries stemming from the investments made in each case, I close the model with respect to households. This means that household consumption is treated as endogenous and therefore included in the intermediate demand account (Wang and Hofe 2007). This is done by attaching the household consumption column and the income row (wages and salaries) to the intermediate consumption matrix.

Technical Coefficients

As explained in Polenske and Fournier (1993), the technical coefficients or direct-input coefficients are used to describe production technology in the input-output methodology. These coefficients are derived by dividing the values in a sector's column of the input-output transactions table, into that sector's output. Each coefficient indicates the amount of each particular input required by a given sector to produce one unit of that sector's output. Technical coefficients provide a quantitative description of the technique of production used by a sector. I then obtained a systematic tabulation of technologies of all sectors of an economy, providing a concise and detailed description of the technological structure of the economy at a given time (Polenske 2006 citing Leontief 1985). For this case-study, I use the 2006 National Account Matrix, which is the latest Colombian input-output table available.

Technological Change in the Liquid Fuels and Gas Supply Sectors

To introduce coal liquefaction and gasification plants in the structure of the Colombian economy, I assume a technological change in both the production of liquid fuels and natural gas. These products have been obtained traditionally from oil and gas operations in Colombia. Nonetheless, new means of production, like coal liquefaction and gasification as proposed in this study, signify a variation in the inputs required by those sectors. For this case-study, I increase the amount of coal needed per unit of output of liquid fuels and gas by modifying the technical coefficients of these sectors relative to the coal sector.

This is done by identifying the proportion of liquid fuels and gas production from coal, out of the total national production of Colombia after the implementation of the plants. Then, I prorate the technical coefficients of the "Fuels" and "Gas Supply" sectors relative to the "Coal" and "Crude Oil and Natural Gas" sectors based on the production proportion. I illustrate this procedure below.

Table 6.8: Fuels Sector Original Technical Coefficients Relative to the "Coal" and "Crude Oil and Natural Gas" Sectors

Sector	Fuels Sector Technical Coefficients
Coal	0.0002
Crude Oil and Natural Gas	0.4456

Source: Author's calculations

Table 6.9: Procedure for the Modification of the Fuels Sector Technical Coefficients

Source of Production	Estimated Liquid Fuels National Production (bbl/day)	National Production Share	Prorated Technical Coefficient
Crude Oil - Refineries	49,000	69%	0.3062
Coal Liquefaction Plant	22,300	31%	0.1394
Total Production	71,300	100%	0.4456

Source: Author's calculations

Table 6.10: Fuels Sector Modified Technical Coefficients

Sector	Fuels Sector Modified Technical Coefficients
Coal	0.1396*
Crude Oil and Natural Gas	0.3062

*Original technical coefficient relative to Coal is added to the prorated coefficient.
Source: Author's calculations

The modified technical coefficient of the Fuels sector relative to the Coal sector (0.1396), is the sum of the original coefficient (0.0002) and the prorated coefficient (0.1394).

I performed the same procedure for the Gas Supply sector:

Table 6.11: Gas Supply Sector Original Technical Coefficients Relative to the Coal and Crude Oil and Natural Gas Sectors

Sector	Gas Supply Sector Technical Coefficients
Coal	0
Crude Oil and Natural Gas	0.1754

Source: Author's calculations

Table 6.12: Procedure for the Modification of the Gas Supply Sector Technical Coefficients

Source of Production	Estimated National Gas Production (MMBtu/day)	National Production Share	Prorated Technical Coefficient
Gas Fields	700,000,000	75%	0.1314
Coal Gasification Plant	234,243,187	25%	0.0440
Total Production:	934,243,187	100%	0.1754

Source: Author's calculations.

Table 6.13: Gas Supply Sector Modified Technical Coefficients

Sector	Gas Supply Sector Technical Coefficients
Coal	0.0440
Crude Oil and Natural Gas	0.1314

Source: Author's calculations.

I replaced the original coefficients with the modified coefficients in the direct-inputs table, to reflect the increase in coal consumption for the production of liquid fuels and gas. I assume that the technical coefficient of the power-generation sector relative to the coal sector remains the same, because power is already being produced in the country from coal.

Technical coefficients for the fuels, gas supply and power-generation sectors are shown in Table 6.14.

The backward linkage is a measure of the interconnection of an industry to other industries from which it purchases its inputs in order to produce its output. An industry has significant backward linkages when its production of output requires substantial intermediate inputs from many other industries (Implan, accessed December 2008. http://implan.com/index.php?option=com_glossary &func=view&Itemid=108&catid=13&term=Backward+linkage).

I obtained the backward linkages for each of the sectors relevant to this analysis by summing their direct-input coefficients. This is useful to estimate which industry has a larger penetration in the whole economy. In this case, the gas-supply sector has the largest backward linkage.

I continue the analysis by deriving the Leontief Inverse, used to determine the coal sector's output, income, and the total economy's output due to the investment demand for each of the coal alternatives considered. These findings are crucial for the selection of the best coal-alternative development from the economic perspective.

Table 6.14: Technical Coefficients for the Fuels, Gas Supply, and Power Generation Sectors used for the Case-study

	SECTOR	Electric Power	Fuels	Gas Supply
	Agriculture, Forestry, Fishing and Hunting	0.0000	0.0000	0.0000
2	**Coal**	**0.0152**	**0.1396**	**0.0440**
3	**Crude Oil and Natural Gas**	**0.0333**	**0.3062**	**0.1314**
4	Metalic Minerals	0.0000	0.0000	0.0000
5	Non-Metalic Minerals	0.0000	0.0000	0.0000
6	Food Production	0.0000	0.0001	0.0000
7	Textile Production and Apparel Manufacturing	0.0003	0.0000	0.0004
8	Wood Products	0.0000	0.0000	0.0000
9	Paper and Carton Products	0.0000	0.0012	0.0000
10	Printing and Editing	0.0019	0.0007	0.0044
11	Oil Refining Products, Fuels	0.0009	0.0292	0.0310
12	Chemical Substances and Products	0.0010	0.0148	0.0040
13	Rubber and Plastic Products	0.0000	0.0035	0.0011
14	Non-Metalic Minerals Products	0.0000	0.0000	0.0000
15	Basic Metallurgic Products (Iron, Steel, Except Machinery)	0.0003	0.0028	0.0105
16	Machinery and Equipment (Transportation Machinery)	0.0499	0.0040	0.1207
17	Furrniture	0.0000	0.0000	0.0000
18	Other Manufactured Goods	0.0001	0.0000	0.0002
19	Waste Products	0.0000	0.0001	0.0000
20	Electric Power	0.3353	0.0005	0.0069
21	Gas Supply	0.0000	0.0000	0.0164
22	Water Supply	0.0001	0.0001	0.0003
23	Building Construction and Machinery Rental	0.0002	0.0001	0.0000
24	Public Works Construction	0.0104	0.0000	0.0018
25	Commerce	0.0000	0.0000	0.0000
26	Transportation (Road, Water, Air)	0.0025	0.0136	0.0042
27	Additional Transportation Services (Storage, Handling)	0.0000	0.0000	0.0031
28	Services to Companies (Finance, Real Estate, Health)	0.0679	0.0198	0.2433
29	Income	0.0926	0.0285	0.0615
	Backward Linkage:	**0.6118**	**0.5647**	**0.6852**

Source: Author's calculations.

I present the Leontief inverse for this analysis in Table B.12. It is obtained by inverting the matrix result of subtracting the technical coefficients matrix from an identity matrix of the same size.

For calculating the coal-sector output and the total output due to the alternative investments, I multiply the Leontief inverse by the exogenous demand vectors for the sectors in which those investments will be made as referred to in the following expression:

$$X = (I - A)^{-1} D$$

In this equation, X is the total output vector, I is the identity matrix, A is the direct-input or technical-coefficients matrix, and D is the exogenous demand, which for this case-study is in the form of investment or stimulus.

For this analysis, investments will be made in the fuels, gas supply, and electric power sectors for coal liquefaction, coal gasification, and intensification of coal-based power generation, respectively. A summary of the investment alternatives is provided in Table 6.15.

Table 6.15: Coal Development Alternative Investments Summary

Coal Development Alternative	Total Capital Investment (Million COP)
Coal-based Power Generation Intensification	6,969,918
Coal Liquefaction	4,292,565
Coal Gasification	4,763,655

Source: Author's calculations.

6.3.2 Input-output Analysis Results

I summarize the input-output analysis results in Table 6.16. For each of the alternatives analyzed, I include the coal-sector output, total output, and, income, in the form of wages and salaries. I will consider these results for the coal-development-alternative decision analysis.

As shown, intensification of power generation is the alternative generating the largest total output and income levels, followed by coal gasification. Coal liquefaction brings the most benefits for the coal sector in terms of output.

I also derived the cost-benefit ratio by dividing each alternatives' total economy output generated, into the total investment. Cost-benefit ratios are shown in Table 6.17.

6.4 Criteria for Project Selection

The framework I propose considers several criteria for the selection of a coal-development alternative. I analyze the economic benefits (i.e., total output and income), environmental performance, and benefits for the coal sector (which are central for this study), in a decision-making process considering a wider range of factors.

Table 6.16: Sectoral and Total Output due to Investments in Coal-Development Alternatives.

Unit: 2006 Millions of Colombian Pesos (COP)

	OUTPUT BY SECTOR	Power Generation	Coal Liquefaction	Coal Gasification
1	Agriculture, Forestry, Fishing and Hunting	521,016	146,412	394,781
2	**Coal**	**205,029**	**653,706**	**278,832**
3	Crude Oil and Natural Gas	471,839	1,530,540	829,761
4	Metalic Minerals	56,503	16,440	62,200
5	Non-Metalic Minerals	17,647	8,289	13,087
6	Food Production	725,165	203,877	549,333
7	Textile Production and Apparel Manufacturing	241,576	69,552	189,650
8	Wood Products	23,370	6,646	18,786
9	Paper and Carton Products	138,065	52,433	131,640
10	Printing and Editing	129,060	38,844	124,906
11	Oil Refining Products, Fuels	239,974	4,578,517	371,843
12	Chemical Substances and Products	580,343	301,443	547,242
13	Rubber and Plastic Products	146,783	83,475	147,538
14	Non-Metalic Minerals Products	63,713	19,204	45,715
15	Basic Metallurgic Products (Iron, Steel, Except Machinery)	421,408	122,985	465,320
16	Machinery and Equipment (Transportation Machinery)	1,154,159	209,803	1,218,071
17	Furniture	24,808	6,843	18,511
18	Other Manufactured Goods	47,438	13,264	36,754
19	Waste Products	30,436	10,663	30,315
20	Electric Power	10,658,357	70,062	210,677
21	Gas Supply	42,012	13,135	4,880,300
22	Water Supply	20,352	6,269	17,186
23	Building Construction and Machinery Rental	29,956	10,147	27,357
24	Public Works Construction	134,851	36,344	30,939
25	Commerce	-	-	-
26	Transportation (Road, Water, Air)	358,417	261,316	327,911
27	Additional Transportation Services (Storage, Handling)	68,998	97,298	86,615
28	Services to Companies (Finance, RE,Health)	2,472,830	757,066	2,787,221
29	**Income (Wages and Salaries)**	**2,252,061**	**615,077**	**1,627,821**
	Total Output	**21,276,166**	**9,939,650**	**15,470,314**

Source: Author's Calculations.

I categorize the factors for the selection of alternatives into three groups: Economic benefits, coal sector benefits, and environmental impacts. The factors contained in these groups and the corresponding performance of the development alternatives, are shown in Table 6.17.

6.4.1 Grid Analysis of the Steam Coal Development Alternatives

Grid analysis is a kind of decision analysis under multiple criteria that aids the decision-making process when various potentially good alternatives are proposed and several factors need to be taken into account to decide among the alternatives. This methodology is intended to choose the alternative that brings about the greatest advantage from the factors' point of view (Mindtools, accessed Nov. 2008, www.mindtools.com/pages/article/newTED_03.htm).

Table 6.17: Coal-Development Alternatives Overall Performance

Group	Factor	Coal Development Alternatives Performance		
		Coal Based Power Generation	Coal Liquefaction	Coal Gasification
Economic Benefits	Total Output (MCOP)	21,276,166	9,939,650	15,470,314
	Income (MCOP)	2,252,061	615,077	1,627,821
	Cost-Benefit	3.05	2.32	3.25
Coal Sector Benefits	Coal Sector Output (MCOP)	205,029	653,706	278,832
Environmental Impacts	CO_2 Emmisions (kg/h)	107,525	25,189	25,189
	Water Consumption (m^3/min)	67.64	2.50	9.39

MCOP = Million Colombian Pesos
Source: Author's Calculations.

I use grid analysis to make a decision based on the performance of the alternatives in each of the criteria described in Section 6.4. This is done by converting the performance results of development alternatives from Table 6.17 into performance indexes reflecting how good a coal development alternative is for a particular factor.

Indexes vary from 1 to 5 and reflect the performance of a development alternative in a factor of decision. The worst is 1, and 5 represents the best possible performance from the alternatives' results. I summarize the indexes and their meaning in Table 6.18.

Table 6.18: Performance Index Meaning Explanation

Index	1	2	3	4	5
Performance	Worst	Not good	Intermediate	Good	Best

Source: Author's Calculations.

To assign an index to a development alternative relative to a specific factor, 20, 40, 60, 80 and 100 percentiles were obtained from the results of all the alternatives in that factor. Then, depending on the percentile gap performance values fall into, performance indexes are given. For instance, 1 is assigned to a 0 - 20 percentile and 5 is assigned to an 80 to 100 percentile. Percentile distribution for all the factors is shown in Table 6.19, and the relationship between percentiles and indexes is described in Table 6.20.

For the environmental factors, namely CO_2 emissions and water consumption, indexes are assigned in the opposite way as higher emissions or water consumption implies a poorer environmental performance. In this sense, 5 would still be the best possible performance, but would correspond to a 0 to 20 percentile (lowest emissions or water consumption), while 1 would correspond to an 80 to 100 percentile (highest emissions and water consumption).

In this framework, water usage should be interpreted in relative terms rather than in absolute terms: The extent of the environmental impacts in a given region due to water consumption, depend on water availability in that region. Higher water consumption does not necessarily entail more adverse environmental impacts as long as water is abundant. Conversely, higher water consumption may signify a deep adverse impact in water-scarce regions because of water depletion. For this case study, I assumed that environmental impacts stemming from water consumption refer to water pollution and not water depletion. Therefore, in this analysis, higher water consumption implies more water pollution from coal transformation processes.

Accordingly, the overall performance indexes for the coal-development alternatives are shown in Table 6.21.

Table 6.19: Percentile Distribution of the Results of Overall Performance for Development Alternatives

Percentiles	20	40	60	80	100
Total Output (MCOP)	12,151,916	14,364,181	16,631,484	18,953,825	21,276,166
Income (MCOP)	1,020,175	1,425,272	1,752,669	2,002,365	2,252,061
Cost-Benefit	2.61	2.91	3.09	3.17	3.25
Coal Sector Output (MCOP)	234,550	264,071	353,807	503,756	653,706
CO_2 Emmisions (kg/h)	25,189	25,189	41,656	74,591	107,525
Water Consumption (m^3/min)	5.26	8.01	21.04	44.34	67.64

MCOP = Million Colombian Pesos.
Source: Author's calculations.

Table 6.20: Scores According to Performance Percentiles

Percentile	0 – 20	20 - 40	40 – 60	60 - 80	80 - 100
Index	1	2	3	4	5

Source: Author's calculations.

Table 6.21: Coal-Development Alternatives' Performance Indexes

Group	Factor	Coal Development Alternatives Performance		
		Coal Based Power Generation	Coal Liquefaction	Coal Gasification
Economic Benefits	Total Output (MCOP)	5	1	3
	Income (MCOP)	5	1	3
	Cost-Benefit	3	1	5
Coal Sector Benefits	Coal Sector Output (MCOP)	1	5	3
Environmental Impacts	CO_2 Emmisions (kg/h)	1	4	4
	Water Consumption (m^3/min)	1	5	3

MCOP = Million Colombian Pesos
Source: Author's calculations.

6.4.2 Scenario Modeling

Scenario modeling is useful to show various outcomes under different circumstances for a set of alternatives. For this case-study, I consider three scenarios that have different priorities for development:

The first scenario prioritizes economic development, making more relevant aspects like the total economy's output and income stemming from the investment stimulus, and the cost-benefit ratio.

The second scenario prioritizes the coal sector development, attributing more weight to the total output of the coal sector.

The third scenario prioritizes environmental conservation, making more relevant factors of ecological impact, including CO_2 emissions and water consumption.

The weights that each scenario attributes to the different factors range from 1 to 5, 1 being irrelevant and 5 being extremely important. I present a summary of the weights and their connotation in Table 6.22, and the scenarios' weights for each factor in Table 6.23.

Table 6.22: Weights and Their Connotation

Weight	1	2	3	4	5
Connotation	Irrelevant	Not Important	Relevant	Important	Extremely Important

Source: Case-study calculations

Table 6.23: Weights for Each Factor of Decision by Scenario

Group	Factor	Priorization by Scenario		
		Economy	Coal Sector Development	Environment Conservation
Economic Benefits	Total Output	5	3	2
	Income	5	3	2
	Cost-Benefit	4	4	2
Coal Sector Benefits	Coal Sector Output	3	5	3
Environmental Impacts	CO_2 Emmisions	1	1	5
	Water Consumption	2	2	5

Source: Author's calculations

The weights reflect what is important for each scenario's perspective without neglecting other factors that have to be taken into account in any case. I assumed that the coal sector output's weight would not be lower than 3 and water consumption's weight would not be lower than 2 for all the scenarios. This is due to the nature of this study, which always emphasizes the sustainable development of the coal sector. Moreover, economic benefits' weights would not be lower than 2 as I assume that development alternatives ought to be economically effective.

6.4.3 Results by Scenario

I determine the total score of each development alternative in a specific scenario, multiplying their overall performance indexes by the weights such scenario attributes to the different factors. Then, I sum the scores for each factor and determine which development alternative gets the higher score, being that alternative the selected one under the given scenario.

I present the results for each scenario considered in Tables 6.24, 6.25, and 6.26.

Scenario of Economy Priority

Table 6.24: Coal-Development Alternatives' Scores for the Economic Priority Scenario

Group	Factor	Coal-Development Alternatives Performance		
		Coal Based Power Generation	Coal Liquefaction	Coal Gasification
Economic Benefits	Total Output	25	5	15
	Income	25	5	15
	Cost-Benefit	12	4	20
Coal Sector Benefits	Coal Sector Output	3	15	9
Environmental Impacts	CO_2 Emmisions	1	4	4
	Water Consumption	2	10	6
	Weighted Score:	68	43	69

Source: Author's calculations.

Under this scenario, the coal-gasification alternative has the higher score, although the power-generation's score is almost the same as that of coal gasification. From this point of view, either development alternative may be undertaken. Yet, coal gasification would be preferred as it entails a smaller environmental footprint.

Scenario of Coal Development Priority

Table 6.25: Coal-Development Alternatives' Scores for the Coal-Development Priority Scenario

Group	Factor	Coal-Development Alternatives Performance		
		Coal-Based Power Generation	Coal Liquefaction	Coal Gasification
Economic Benefits	Total Output	15	3	9
	Income	15	3	9
	Cost-Benefit	12	4	20
Coal Sector Benefits	Coal Sector Output	5	25	15
Environmental Impacts	CO_2 Emmisions	1	4	4
	Water Consumption	2	10	6
	Weighted Score:	50	49	63

Source: Author's calculations.

In the scenario shown in Table 6.25, coal gasification gets the higher score, well above the other two alternatives. Even though coal liquefaction has a better performance in the coal sector output, coal gasification still benefits the coal sector with no drawbacks relative to other factors and a better overall performance.

Scenario of Environmental Conservation Priority

Table 6.26: Coal-Development Alternatives' Scores for the Environmental Conservation Priority Scenario

Group	Factor	Coal-Development Alternatives Performance		
		Coal-Based Power Generation	Coal Liquefaction	Coal Gasification
Economic Benefits	Total Output	10	2	6
	Income	10	2	6
	Cost-Benefit	6	2	10
Coal Sector Benefits	Coal Sector Output	3	15	9
Environmental Impacts	CO_2 Emmisions	5	20	20
	Water Consumption	5	25	15
	Weighted Score:	39	66	66

Source: Author's calculations.

For the scenario shown in Table 6.26, coal liquefaction and coal gasification have the same score. This means that under this scenario, either development alternative could be undertaken. The results also show that coal-based power generation is definitively the least-appealing alternative from the environmental point of view, having the highest carbon emissions and water consumption of the three choices.

Policy making about the kind of development alternative to implement in this framework, depends on the priorities for development that the governmental agency making the decision about what alternative to foster would have, or the kind of scenario considered.

However, from the previous analysis, I select for this study coal gasification as the development alternative that should be implemented, since it has the best performance for all three criteria, integrating the development of the coal sector with very positive economic effects, with the lowest environmental impact.

6.5 Geographic Information Systems Applied to the Strategy Making

In this stage of the analysis, Geographic Information Systems (GIS) may provide valuable information to plan the set-up and development of a given alternative for the medium-scale coal sector. For this study, I focus on finding the best possible locations for the development of a coal-gasification project, based on proximity to coal deposits, water sources and roads, and proximity to distribution infrastructure, such as gas pipelines. I use *Suitability Analysis*, a GIS-based procedure, which combines these factors to determine the most suitable areas for project development.

6.5.1. Suitability Analysis for Project Location

To conduct a suitability analysis for coal gasification, it is necessary to have a complete set of data that fundamentally includes coal-deposit characteristics and location, infrastructure for transportation of inputs, and distribution of outputs, terrain characteristics, water sources, and protected areas.

The datasets that I used for this analysis contain:

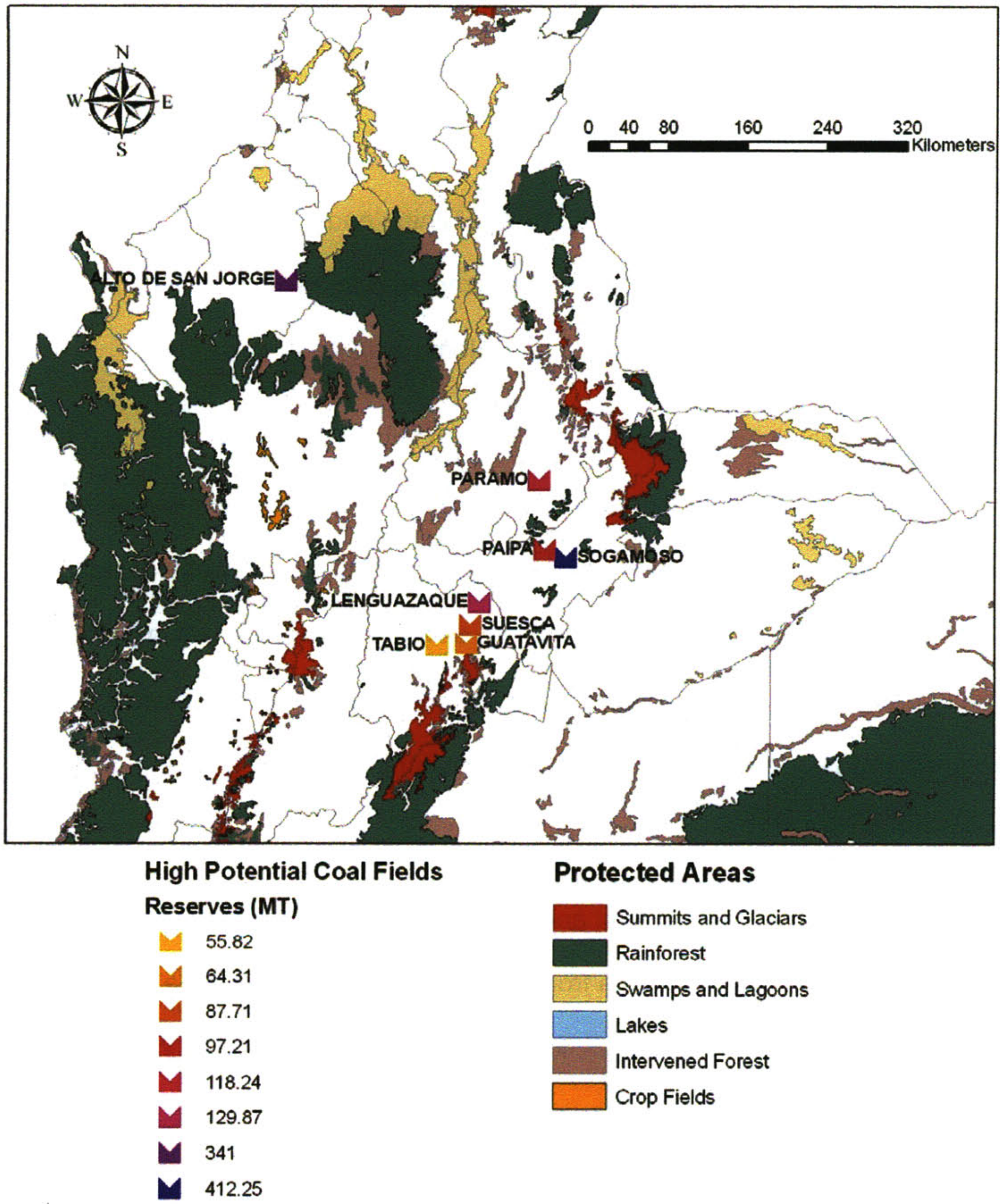
- Coal reserves and location
- Primary and secondary roads
- Gas pipelines
- Rivers
- Protected Areas

These datasets were kindly provided by the Mining and Energy Planning Unit (UPME) from the Colombian National Geographic Database, managed by the Agustin Codazzi Geographic Institute of Colombia (IGAC).

I began the analysis by selecting from the Colombian GIS dataset, the coal fields with high potential for development from the point of view of measured reserves and coal quality, as indicated in Chapter 5. I also verified that selected coal fields would not overlap protected areas since no development is allowed in Summits and Glaciers areas and development is extremely restricted in Rainforest, Swamps and Lagoons, and Lake areas. I present these coal fields and protected areas in Figure 6.1

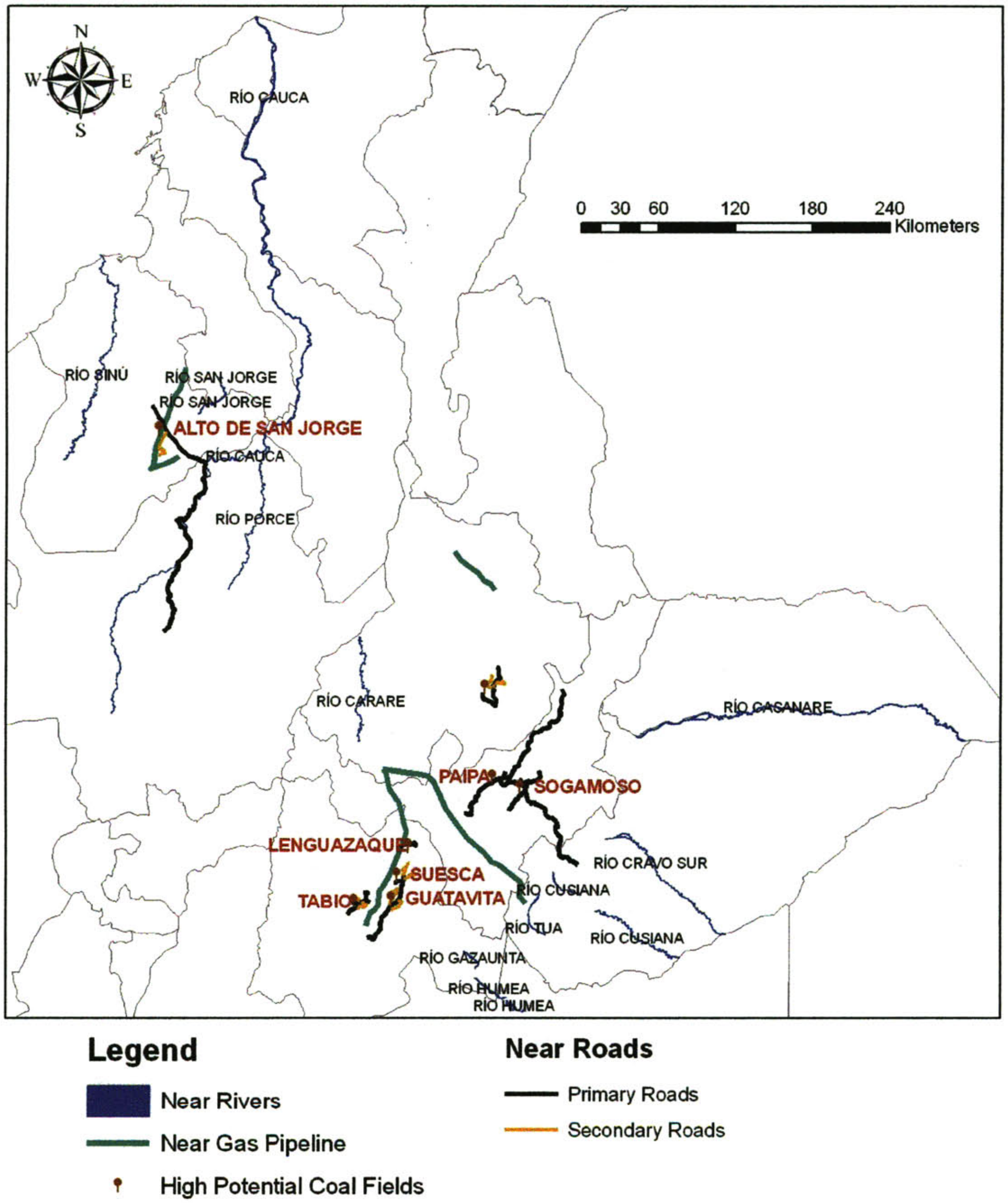
Then, I selected the roads, rivers, and gas pipelines closest to the coal fields. To do this, I created distance buffers from the coal fields and picked the features that were intersected by such buffers. I show these features in Figure 6.2.

After, I created distance gradients representing the proximity to coal fields, roads, rivers, and gas pipelines. Darker shades indicate higher attractiveness for location due to shorter distance from coal fields to each of these features. Conversely, lighter shades indicate lower attractiveness for location as distances from features are longer. I present the attractiveness for location considering proximity to coal fields and roads, rivers and pipelines in Figures 6.3, 6.4 and 6.5 respectively.



Source: IGAC - Colombian GIS Database (2008). Built by Author.

Figure 6.1: Coal Fields with High Reserve-Potential and Protected Areas in Colombia



Source: IGAC - Colombian GIS Database (2008). Built by Author.
Río = River

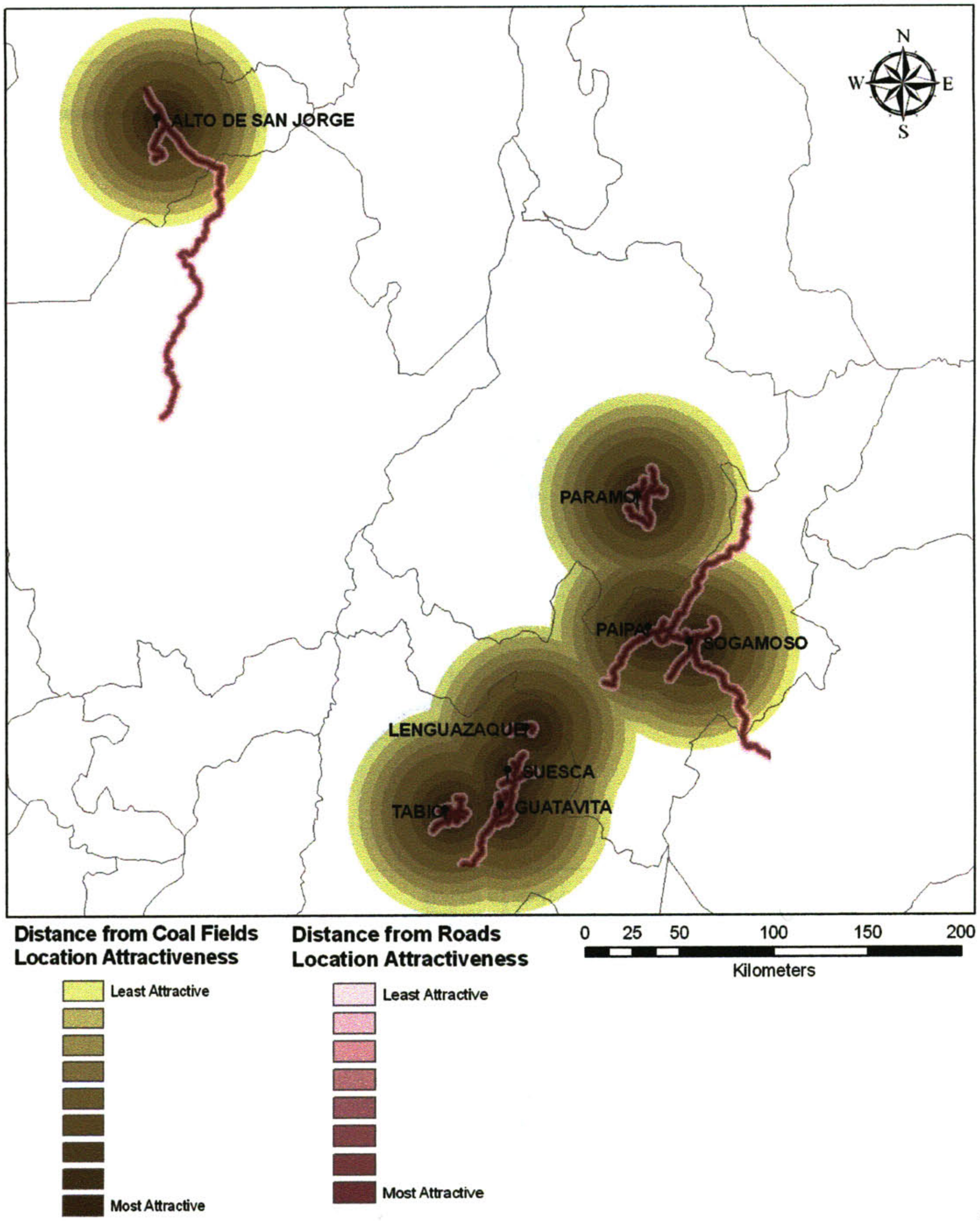
Figure 6.2: Nearest Roads, Rivers and Gas Pipelines to High Potential Coal Fields.

Later, I created a weighted overlay combining the location attractiveness for each feature, in order to identify areas with the highest suitability for location based on the proximity to coal and water sources, and infrastructure. I show the final suitability map in Figure 6.7. As portrayed in the map, dark blue represents the most suitable areas for the development of the coal gasification project and light yellow indicate the least suitable areas.

In the weighted overlay shown in Figure 6.6, I assign a higher relevance to the proximity to coal fields and rivers as I assume that being close to raw materials sources would be preferable to diminish infrastructure and transportation costs.

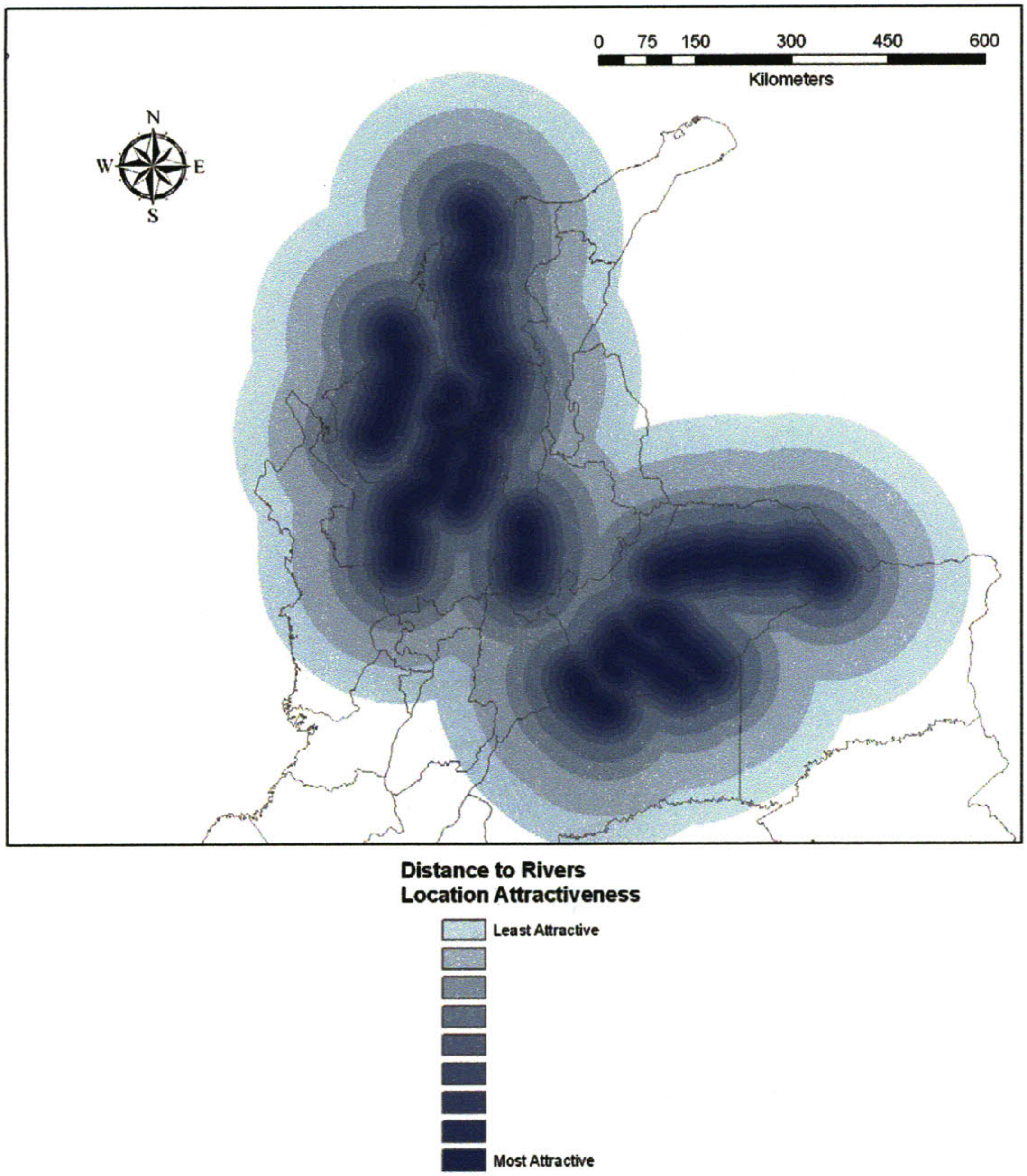
Location considerations in this particular procedure emphasize a local perspective, as the infrastructure considered was the closest to mining fields described for domestic consumption. In a higher scope of analysis, proximity to coastal ports should also be considered to evaluate the convenience of coal and coal-based products exports and the development of supporting infrastructure for this purpose.

Finally, I overlaid the Colombian municipalities to identify where the coal gasification development should take place. As shown in Figure 6.7, for the San Jorge coal field, the municipalities of interest are Buenavista, Planeta Rica and La Apartada.



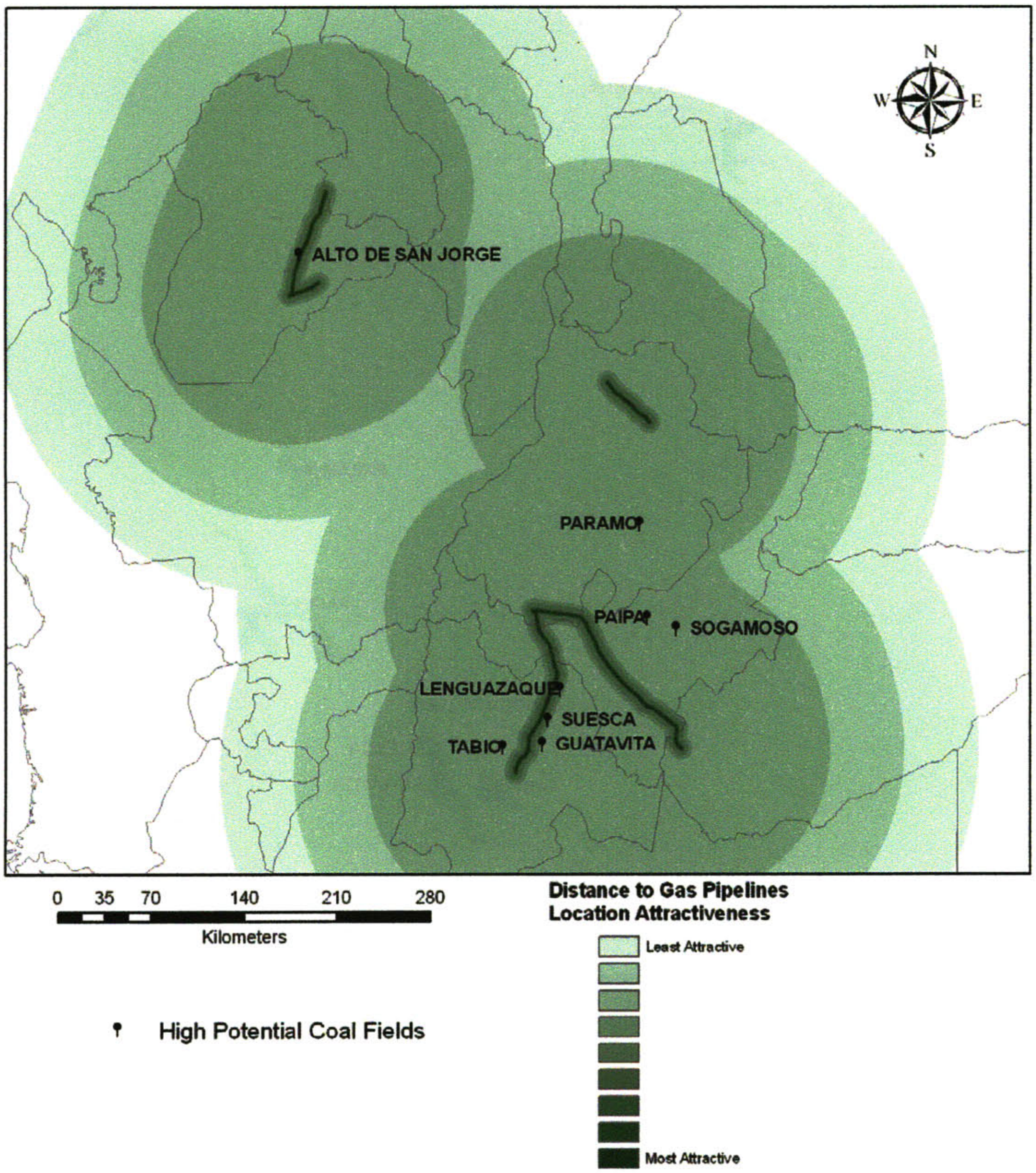
Source: IGAC - Colombian GIS database (2008). Built by: Thesis Author

Figure 6.3: Location Attractiveness Based on Distance from Coal Fields and Near Roads



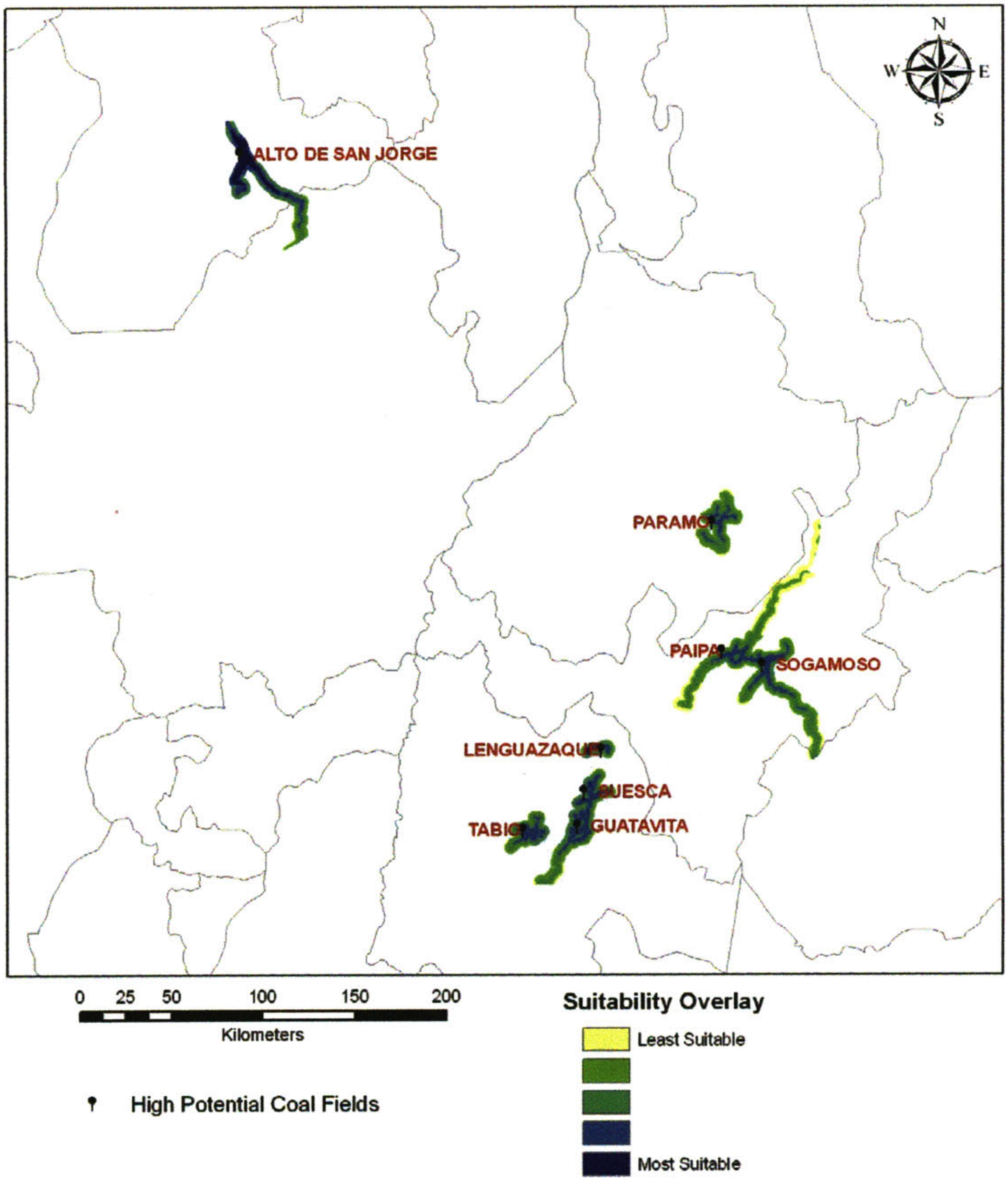
Source: IGAC - Colombian GIS Database (2008). Built by Author.

Figure 6.4: Location Attractiveness Based on Distance from Rivers.



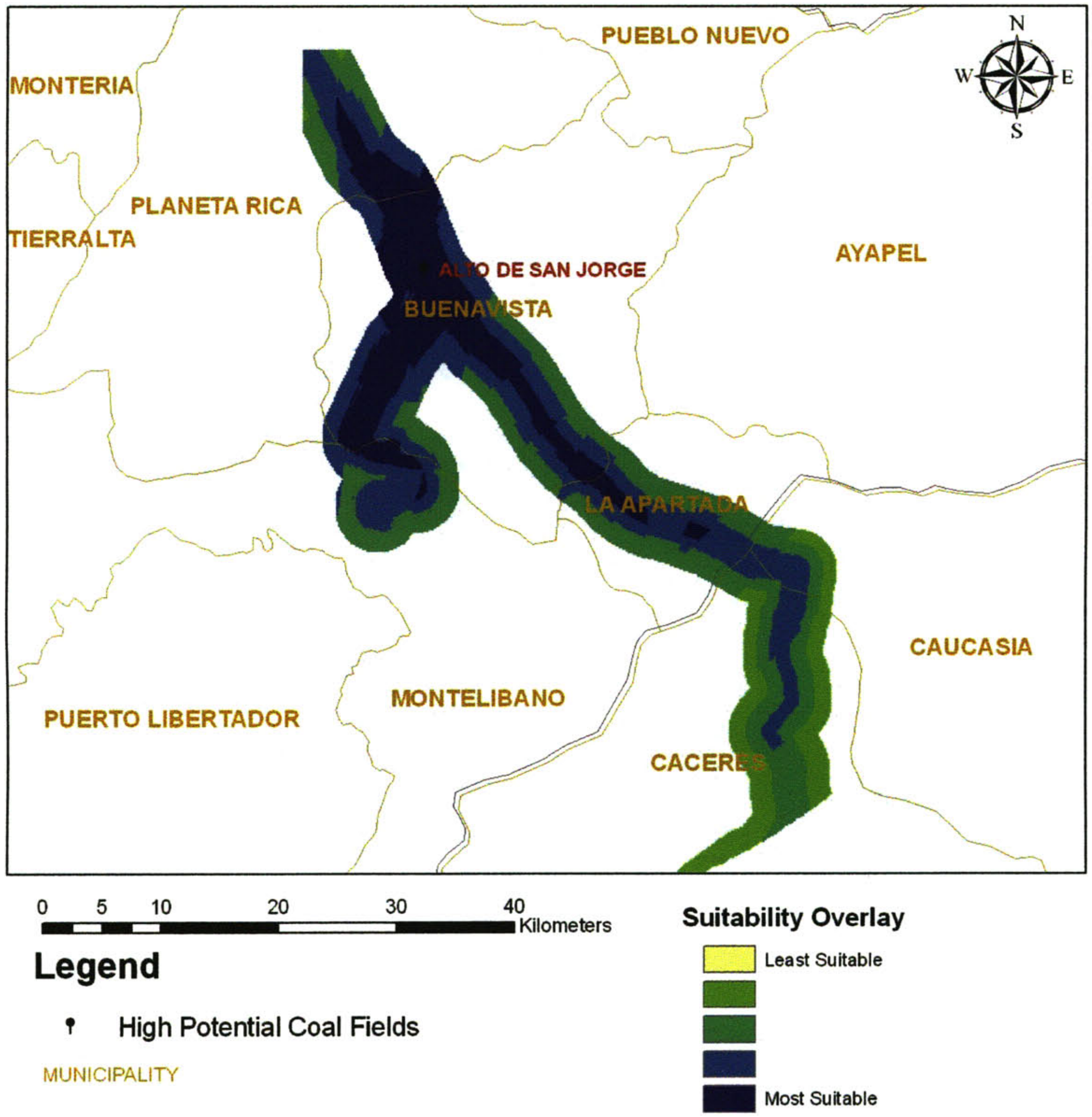
Source: IGAC - Colombian GIS Database (2008). Built by Author.

Figure 6.5: Location Attractiveness Based on Distance from Gas Pipelines



Source: IGAC - Colombian GIS Database (2008). Built by Author.

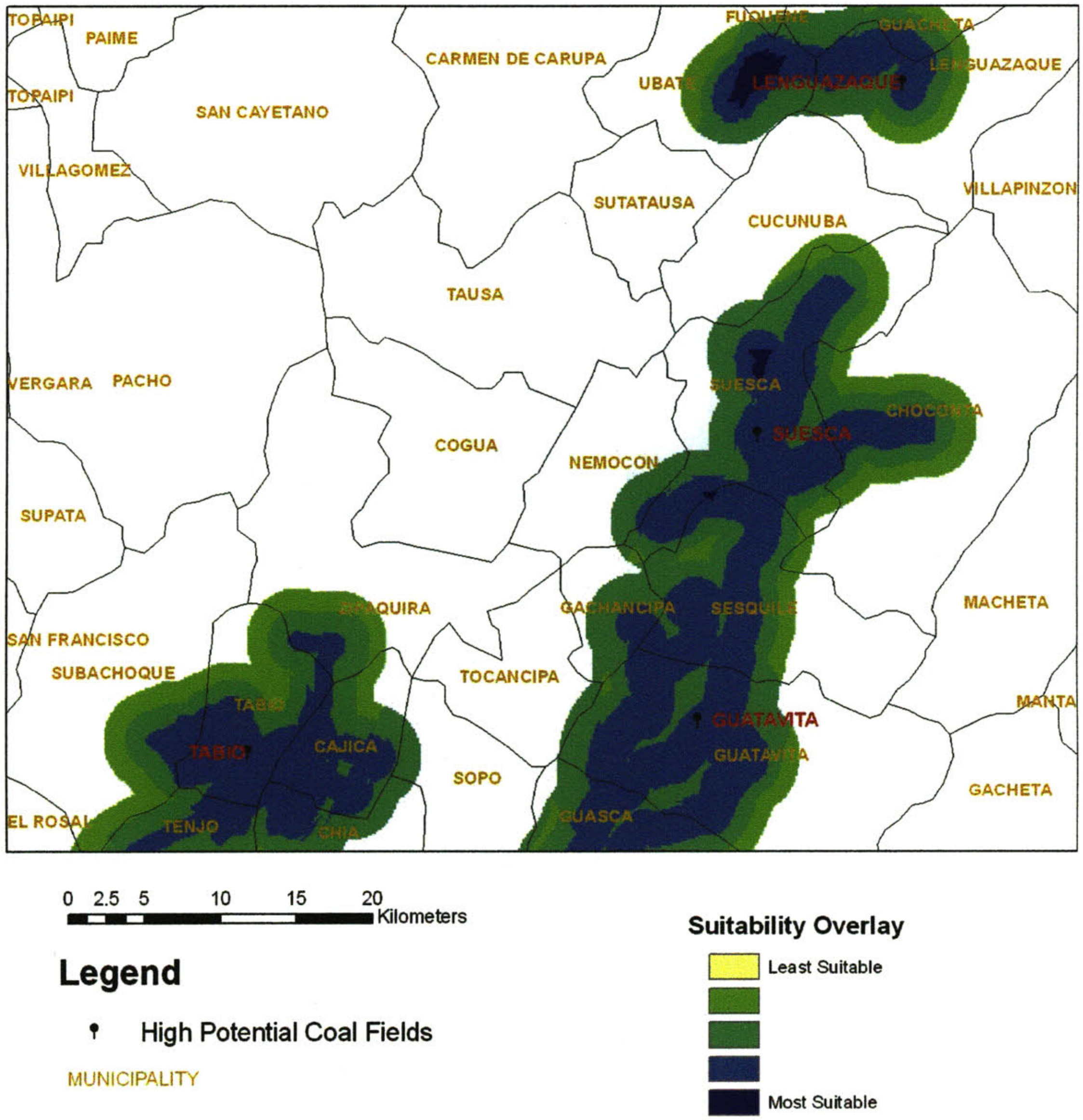
Figure 6.6: Location Suitability Overlay for Coal Gasification



Source: IGAC - Colombian GIS Database (2008). Built by Author.

Figure 6.7: Suitability Overlay for the San Jorge Coal Field

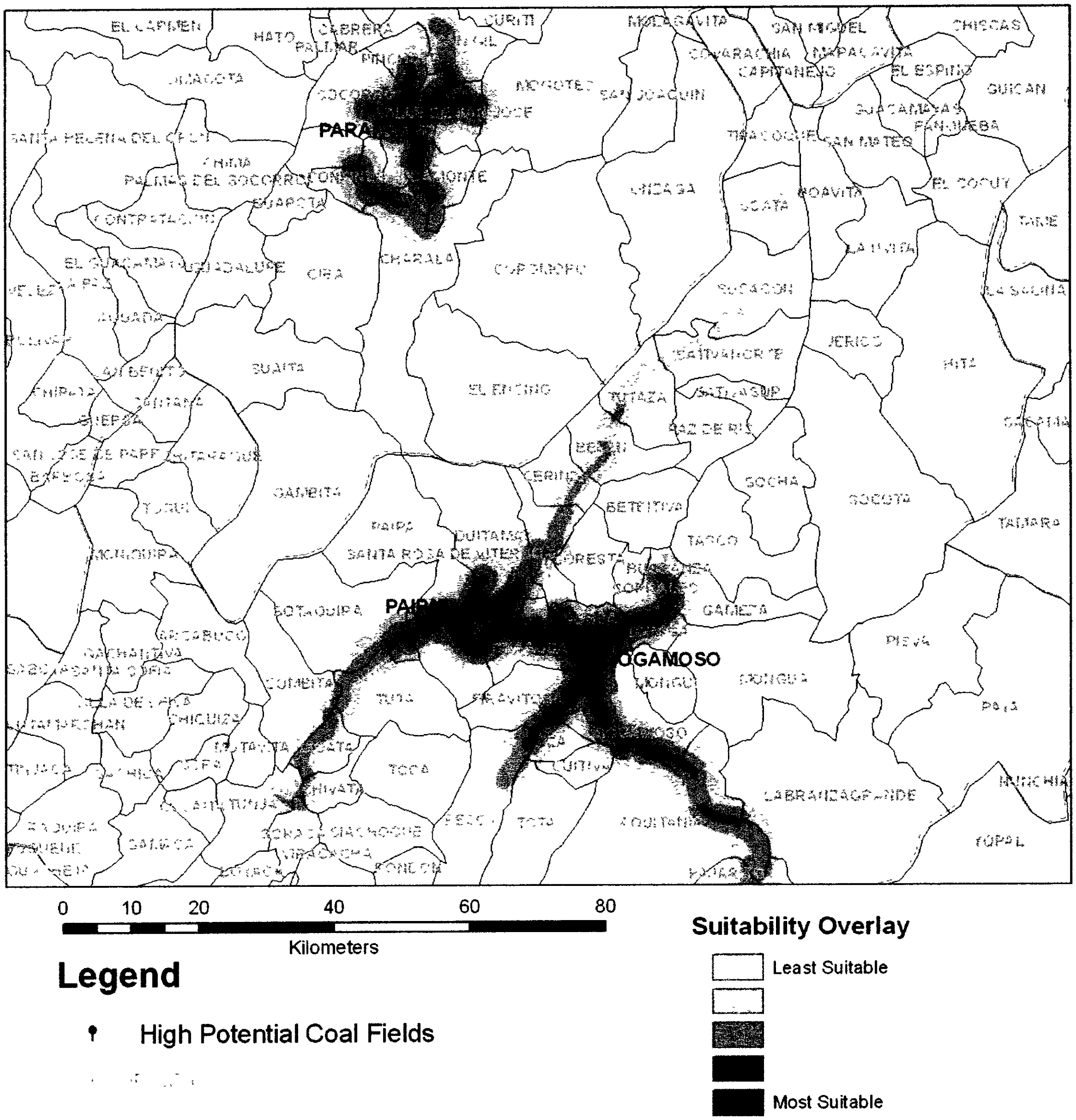
I present the municipalities of interest for the Suesca and Lenguazaque coal fields in Figure 6.8.



Source: IGAC - Colombian GIS Database (2008). Built by Author

Figure 6.8: Suitability Overlay for the Suesca and Lenguazaque Coal Fields

The rest of coal fields have a lower suitability for coal gasification development. However, I present in Figure 6.9 the municipalities of interest for an eventual coal gasification development for these fields.



Source: IGAC - Colombian GIS Database (2008). Built by Author

Figure 6.9: Suitability Overlay for the Paipa and Sogamoso Coal Fields

6.6 Coking Coal Development Alternatives

In this section, I analyze from the macroeconomic point of view the stream of benefits from two alternatives proposed for the development of the coking coal industry: Intensification of coking-coal exports and intensification of national steel production using coke.

I conduct an input-output analysis using the same national accounts matrix and procedure described in Section 6.3 to compare the coal sector output, national total output and income generated by each coking coal development alternative.

Unlike the analysis conducted for steam coal, this analysis is intended exclusively to understand if either, expanding coking coal mining and exports, or increasing the processing of coking coal locally to produce much higher value-added products (i.e., steel), brings about more benefits to the Colombian economy.

Based on the analysis outcome, decision-makers will have information to support choices about fostering coking coal exports or the local consumption of coking coal for steel making.

6.5.1 Analysis Overview

In order to analyze the "round-by-round" effect of coking-coal exports and coking-coal domestic consumption increase, I use the same input-output procedure described in Section 6.3. As for the steam-coal-development alternatives, I close the model with respect to households to identify the income generated by each alternative.

I consider an exogenous demand applied directly to the coal sector to represent the increase in exports. I assume the demand to be the product of an exporting target of four million tonnes of coking coal by its 2006 FOB average price. In 2006 coking-coal prices varied from USD 90.08 to USD 91.90. Therefore, I assumed an average 2006 price of USD 90.70 per metric ton (Steel on the net. Accessed on December 2008 www.steelonthenet.com/files/metallurgical_coal.html). Then I converted the total four Mt FOB USD value into Colombian Pesos, using the exchange rate of 2361,14 COP per 1.00 USD (Nationmaster 2008).

Moreover, to analyze the case of local coking-coal consumption, I assume the same value as an exogenous stimulus to the Basic Metallurgic Products sector for the purpose of comparing the stream of benefits of both alternatives to the coal sector, income and the economy's total output.

I also assume that the consumption structure and technologies of both sectors do not change and therefore, the direct-input coefficients remain unchanged. The technical coefficients are included in Table 6.27.

Table 6.27: Coal Sector and Basic Metallurgic Sector Technical Coefficients

	SECTOR	Coal	Basic Metallurgic Products
1	Agriculture, Forestry, Fishing and Hunting	0.0000	0.0001
2	Coal	0.0174	0.0018
3	Crude Oil and Natural Gas	0.0000	0.0000
4	Metalic Minerals	0.0000	0.1303
5	Non-Metalic Minerals	0.0001	0.0005
6	Food Production	0.0000	0.0000
7	Textile Production and Apparel Manufacturing	0.0006	0.0002
8	Wood Products	0.0000	0.0019
9	Paper and Carton Products	0.0008	0.0042
10	Printing and Editing	0.0002	0.0048
11	Oil Refining Products, Fuels	0.0825	0.0148
12	Chemical Substances and Products	0.0167	0.0204
13	Rubber and Plastic Products	0.0142	0.0108
14	Non-Metalic Minerals Products	0.0000	0.0038
15	Basic Metallurgic Products (Iron, Steel, Except Machinery)	0.0000	0.3393
16	Machinery and Equipment (Transportation Machinery)	0.0384	0.0161
17	Furniture	0.0000	0.0000
18	Other Manufactured Goods	0.0000	0.0000
19	Waste Products	0.0000	0.0218
20	Electric Power	0.0086	0.0202
21	Gas Supply	0.0000	0.0034
22	Water Supply	0.0001	0.0005
23	Building Construction and Machinery Rental	0.0019	0.0002
24	Public Works Construction	0.0439	0.0000
25	Commerce	0.0000	0.0000
26	Transportation (Road, Water, Air)	0.0436	0.0214
27	Additional Transportation Services (Storage, Handling)	0.1019	0.0005
28	Services to Companies (Finance, RE,Health)	0.0639	0.0532
29	Income	0.0719	0.0666
	Backward Linkage	0.5067	0.7368

Source: Author's calculations

I summarize the exogenous demand for each development alternative in Table 6.28.

Table 6.28: Exogenous Demands for Coking-Coal Exports and Coking-Coal Local Consumption from Steel Making

Coking-Coal Development Alternatives	
Target Coking Coal Exports (Tonnes)	4,000,000
Coking Coal 2006 FOB price range (USD/t)	90.08 – 91.90
Assumed Average 2006 FOB Price (USD/t)	90.70
2006 FOB Price (COP/MT - ExRate = 2361.14)	214,155
Total Exogenous Demand for Exports (MCOP)	856,622
Exogenous Demand for Steel Making	856,622

FOB = Free on Board
Source: Author's calculations
Note: Total exogenous demand for exports and Exogenous demand for steel making are identical due to the consideration in Section 6.5.1.

I followed the same procedure described in Section 6.3.1 to obtain the income, coal sector output, and total output due to the exogenous demand in the coal sector and basic metallurgic products sector from the investments on coking-coal exports intensification and steel-making intensification. respectively. I present the results of this analysis in Table 6.29.

Table 6.29: Exogenous Demands for Coking-Coal Exports and Coking-Coal Local Consumption from Steel Making

	SECTOR	Coal	Basic Metallurgic Products
1	Agriculture, Forestry, Fishing and Hunting	61,330	64,751
2	**Coal**	**889,411**	**16,976**
3	Crude Oil and Natural Gas	39,910	28,371
4	Metalic Minerals	7,505	174,307
5	Non-Metalic Minerals	3,716	3,617
6	Food Production	84,726	86,489
7	Textile Production and Apparel Manufacturing	29,093	29,163
8	Wood Products	3,641	5,522
9	Paper and Carton Products	21,475	26,453
10	Printing and Editing	15,752	21,100
11	Oil Refining Products, Fuels	113,476	72,992
12	Chemical Substances and Products	101,771	121,801
13	Rubber and Plastic Products	33,436	35,753
14	Non-Metalic Minerals Products	12,447	11,813
15	Basic Metallurgic Products (Iron, Steel, Except Machinery)	56,167	1,336,273
16	Machinery and Equipment (Transportation Machinery)	103,319	93,055
17	Furniture	2,882	2,904
18	Other Manufactured Goods	5,498	5,512
19	Waste Products	4,370	32,732
20	Electric Power	36,181	67,920
21	Gas Supply	5,423	11,057
22	Water Supply	2,446	2,918
23	Building Construction and Machinery Rental	5,725	3,632
24	Public Works Construction	45,369	2,339
25	Commerce	0	0
26	Transportation (Road, Water, Air)	80,541	70,960
27	Additional Transportation Services (Storage, Handling)	101,006	11,360
28	Services to Companies (Finance, Real Estate, Health)	316,975	301,629
29	**Income**	**257,866**	**263,090**
	Total Output	**2,441,457**	**2,904,487**

Source: Case-study Calculations

6.5.2 Coking-Coal Development Analysis Conclusions

From the economic point of view, the "ripple effect" of both alternatives on the economy, are not too far from each other, in terms of income and total output generated. Nonetheless, the steel-making stimulus generates more economic benefits as the backward linkage of this sector is larger than that of the coal sector.

Moreover, the benefit that a stimulus on steel making generates to the coal sector, is much lower than that generated by an increase in coking-coal exports. The explanation for this result is that the direct, indirect, and induced effects of coking-coal exports on the coal sector are much larger than those of the steel making industry. In addition, coking-coal consumption from the steel making industry will be limited by the input-structure and production capacity of national steel plants.

In the analysis for coking-coal-development alternatives, I do not consider environmental performances quantitatively, due to time constraints for data gathering.

In conclusion, in a coal-sector-development-priority scenario, coal-exports intensification is the best option, since it provides the highest benefits to the coal sector and has very positive effects on income and total output of the economy. The challenge to undertake this development is to implement the supporting infrastructure to increase transportation efficiency and reduce the transportation cost.

In a scenario of economic priority, intensification of steel making would be the best alternative, as it generates the most economic advantages in terms of income and total output. Nevertheless, serious environmental controls must be implemented for this alternative, since coke making for steel production is a highly polluting and water-consuming activity.

6.7. Summary

I conducted a case study using the proposed framework for finding and evaluating coal-development alternatives for the medium-scale coal sector in Colombia. This case study has the purpose of illustrating the frameworks' criteria, components. and its functioning.

I used input-output analysis and multi-criteria-decision analysis to devise the most appropriate steam-coal-development alternative from the economic and environmental perspectives. Also, I used GIS analysis to determine the coal-fields project location suitability for the development of a coal-gasification project.

In addition, I compared two coking-coal-development alternatives, namely intensification of coking-coal exports and intensification of coke production for steel making from the economic perspective using input-output analysis. multi-criteria decision and GIS analyses as data for these procedures could not be easily acquired.

CHAPTER 7

CONCLUSIONS

Here, I review the study's fundamentals, outcome, and value for finding development alternatives for the medium-scale coal sector in Colombia.

In this study, I have devised a framework to find development alternatives for the medium-scale coal sector in Colombia, taking into account the country's requirements for its socioeconomic growth, the government's efforts to enhance the competitiveness and productivity of the country, the advancement of the coal sector in Colombia, and ways to contribute to environmental sustainability.

In the design of this framework, my goal was to find coal-development alternatives for the underdeveloped coal areas in Colombia, that offset the constraints for development of the medium-scale coal sector, and at the same time, secure strategic supplies that the country needs for its competitiveness and productivity enhancement.

The coal-development alternatives found include intensification of coal-based power generation, coal liquefaction and coal gasification. I identified the economic and environmental performance of these alternatives for a target coal consumption of four million tonnes per annum, as that is the scale of the coal-mining development that I assumed. I evaluated these alternatives individually from the macroeconomic point of view using input-output analysis, to determine their "ripple effect" on the economy. Furthermore, I used multi-criteria decision analysis to integrate the environmental performance of the coal development alternatives and identified the most appropriate project from the point of view of different scenarios that prioritize economic development, development of the coal sector, or environmental conservation. Later, I used Geographic Information Systems (GIS) to conduct suitability analysis for location of the coal-development alternative that I selected, which is coal gasification.

From this study, I draw the following conclusions:

- The Framework for the Development of the Medium-Scale Coal Sector in Colombia, is a practical tool for decision-makers of the coal sector in the country, to envision activities that advance the coal sector and the national economy, reducing the environmental impacts of the coal industry's development.
- The framework sheds light on-coal development alternatives that are economically and environmentally sustainable and that will provide strategic supplies for the country's development
- Development alternatives must ensure a constant, long-term demand for coal to achieve economies of scale in mining activities, in order to have significant impacts in the coal sector and the economy.
- The integrative planning scope of the framework helps planners to identify the most appropriate medium-scale coal development alternative from the economic and environmental standpoints simultaneously by combining several decision factors.

- Methodologies involved in this framework, assist decision-makers, integrating a wide range of criteria and prioritization policies for development.

- Input-output analysis is a valuable planning tool that made it possible, in this analysis, to determine and take into account the effects of changes in the coal sector and exogenous stimuli of other sectors on the Colombian economy, providing crucial information for decision makers.

- Spatial analysis with geographic information systems (GIS), is a dynamic planning tool that may provide logistics' costs estimations and additional environmental performance measures, which are useful for the economic and environmental evaluation of coal-development alternatives. After an analyst identifies an alternative, GIS may assist the project-planning process.

  I used GIS in this study to identify the location suitability of coal regions for project development, based on proximity to inputs (coal and water) and proximity to available infrastructure. As the coal-development alternatives included in this study are intended for domestic consumption, the scope of the analysis was local and emphasized proximity to coal fields. In a further stage, a wider-scope GIS analysis may integrate coastal ports to determine the feasibility of coal exports from the interior of the country, analyzing the required expansion of supporting infrastructure for this purpose.

- Coal gasification provides the most advantage from the economic and environmental perspectives combined. In addition, other coal-development alternatives can be based on gasification, as it is the stepping stone for the production of other coal-based supplies.

Further work from this study may include the determination and integration in the analysis of transportation and distribution costs for each coal-development case using GIS analysis. Additionally, in an implementation stage, GIS analysis can be conducted to determine required supporting infrastructure for the development of alternatives.

Finally, this framework can be applied to other non-renewable and renewable resources in Colombia, to design development strategies that contribute to the improvement of the country's sustainable development and socioeconomic advancement.

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APPENDICES

Appendix A: Appendix to Chapter 5.

Table A.1: Coal Production Series per Province and Mining Company until June 30/2008

Province	2004 Tonnes	2005 Tonnes	2006 Tonnes	2007 Tonnes	2008 Tonnes
Antioquia ALL COMPANIES	351.822,46	488.228,82	427.562,93	230.132,59	83.008,66
Boyacá	1.204.223,26	1.280.126,56	1.756.381,02	2.275.218,07	1.180.117,18
Casanare				119,06	
Cauca	26.778,35	43.988,12	28.800,76	17.881,02	5.775,84
Cesar* CARBOANDES S.A.	394.302,15	684.646,12	1.315.612,58	325.607,69	
CARBONES DE LA JAGUA		1.836.180,63	1.942.384	2.625.172,04	861.983,54
CARBONES DEL TESORO S.A.				1.209.728,07	
CARBONES EL TESORO S.A.					1.113.925,1
CARBONES SORORIA LTDA - AREA SORORIA	32.919,1	149.769,61	422.890,31		
C.I. PRODECO S.A.	612.258	1.502.201,48	2.878.837	3.725.148,08	2.069.681
COMPAÑIA CARBONES DEL CESAR				1.461.580,67	
COMPAÑIA CARBONES DEL CESAR S.A.					749.936,66
CONSORCIO MINERO UNIDO S.A.	1.070.900	1.349.289	1.478.068,49	551.687,02	0
DRUMMOND LTD - AREA LA LOMA	20.454.159	21.463.755	21.619.595	22.898.182	11.275.524
EMCARBON S.A.					774.372,45
LA JAGUA COAL COMPANY	2.386.609,71				
NORCARBON S.A. - AREA LA DIVISA	77.230,16	723.661,46	1.460.897	389.460,2	247.185,51

Source: Sistema de Información Minero Colombiano – SIMCO (2008).
Notes: *Steam Coal for Exports. Numbers are expressed in Colombian number format, using as thousand separator a point (.) and as decimal separator a comma (,).

Table A.2: Coal Production Series per Province and Mining Company until June 30/2008 (Continued)

Province	2004 Tonnes	2005 Tonnes	2006 Tonnes	2007 Tonnes	2008 Tonnes
Córdoba CARBONES DEL CARIBE - AREA LA GUACAMAYA	351.013,98	183.256,09	512.116,63	480.964,98	266.595,48
Cundinamarca TODAS LAS EMPRESAS	916.464	1.176.306	1.074.017,48	1.784.737,22	1.095.295,57
La Guajira* CARBONES COLOMBIANOS DEL CERREJON - AREA LA COMUNIDAD	600.5	736.5	834.5	733.944,67	1.286.362
CARBONES DEL CERREJON - AREA LA COMUNIDAD	2.307.079	1.777.295	2.955.527	2.797.639	1.035.074,17
CARBONES DEL CERREJON - AREA OREGANAL	1.180.972	1.002.896	1.103.059	2.047.185	1.626.985
CERREJON ZONA NORTE	14.674.000	18.782.045	19.002.738	19.002.202	9.367.700
CONSORCIO CERREJON - AREA PATILLA	5.784.242	4.881.293	5.177.661	5.488.481	2.459.217
Norte de Santander ALL COMPANIES	1.283.265	1.403.594,23	1.931.271,35	1.691.285,21	1.010.484,67
Santander	179.323,49	210.067,28	112.611,27	116.287,67	99.256,35
Valle del Cauca	450	0	157.332,28	49.559,16	10.470,82

Source: Sistema de Información Minero Colombiano – SIMCO (2008)..
Notes: *Steam Coal for Exports. Numbers are expressed in the Colombian number format, using as thousand separator a point (.) and as decimal separator a comma (,).

Table A.3: Qualities of Coal in Colombia per Province and Areas

ZONE	AREA	SECTOR	BASE	MOISTURE		ASH	VM	FC	St	CV	CV	CV
					%	%	%	%	%	BTU/Lb	MJ/kg	kcal/kg
La Guajira	Cerrejón norte		ROM	Eq + 1	11.94	6.94	35.92	45.2	0 43	11,586	27,00	6,440
	Cerrejón Central											
	Cerrejón Sur											
Cesar	La Loma	Sinclinal La Loma El	ROM	Eq + 1	11 39	10.32	33 37	66 63	0 72	10.867	25.32	6,040
		Boquerón	ROM	Eq. + 11/2	10.29	5.61	36.79	47 31	0 59	11,616	27.07	6,450
		El Descanso Sur										
	La jagua de Ibirico	La Jagua	ROM	Eq + 1 1/2	7.14	5.32	35.7	51 84	0.62	12,606	29 37	7,000
		Cerro Largo										
Córdoba-Norte de Antioquia	Alto San jorge	San Pedro Sur	BCA	HR	14 49	9.24	37 55	38 73	1 31	9,280	21.62	5,160
		San Pedro Norte	BCA	HR	14.49	9.24	37 55	38 73	1.31	9,280	21.62	5,160
		Alto San Jorge	BCA	HR	14.49	9.24	37.55	38 73	1 31	9.280	21.62	5,160
Antioquia - Antiguo Caldas	Venecia - Fredonia		ROM	Eq + 1	11 64	8 11	40.06	40 2	0.48	10,426	24.29	5,790
	Amagá - Angelópolis	Amagá -Nechí	ROM	Eq + 1	13 16	11.96	36.69	38 18	0 55	9,682	22.56	5,380
		Angelopolis										
Antioquia - Antiguo Caldas	Venecia - Bolombo	Rincón Santo	BCA	HR	9.84	11.1	38.45	40.61	1.04	10,090	23 51	5,610
		Bolombo	BCA	HR	8.49	7.9	37 77	45 91	1.09	11,113	25.89	6,170
	Titiribí	Corcovado	ROM	Eq. + 1	7.25	7.92	37.99	46.84	0.72	11,767	27.42	6,540
		El Balsal										
	Río Sucio - Quinchía		BCA	HR	4 08	15.56	31 75	48 61	1.8	10,713	24.96	5,950
	Aranzazu - Santágueda	Aranzazu	BCA	HR	22 22	28.69	30.33	18 76	0.67	5,451	12.70	3,030
		Santágueda	BCA	HR	19.03	25.05	37.32	18.6	0 43	6,230	14.52	3,460
Valle del Cauca - Cauca	Yumbo - Asnazú	Golondrinas - Río Cañaveralejo	ROM	Eq. + 1	2.69	22.38	28 15	46.79	2.85	11,088	25.84	6,160
		Cañaveralejo-Río Pance										
		Río Pance-Río Guachinte										
		Río Guachinte-Río Asnazú										
	Río Dinde - Quebrada honda		ROM	Eq + 1	2.83	20.63	36.72	40	4 02	11,138	25.95	6,190
	Mosquera - El Hoyo	Pedregosa-Mosquera	ROM	Eq + 1	8 11	16 3	35 18	40 42	1 42	10,058	23.44	5,590
		Limoncito-Yeguas										
		El Vergel										
		Guilacé-El Hoyo										
Cundinamarca	Jerusalén - Guataquí		BCA	HR	5 19	5.34	39.09	50 38	0 58	13,044	30.39	7,250
	Guaduas - Caparrapí	Caparrapí	BCA	HR	4 12	5.61	22.43	67 83	0 59	12,829	29.89	7,130
		Guaduas										
	Guatavita-Sesquilé-Chocontá	Suesca-Chocontá	BCA	HR	1.98	11.23	34.88	51.91	0.91	12,682	29.55	7,050
		Guatavita										
	Tabio- Río Frío- Carmen de Carupa	Carmen de Carupa	ROM	Eq + 2	3 42	12.67	20 8	63.1	1 53	13,041	30.39	7,250
		Tabio-Río Frío	ROM	Eq + 2	4 12	9 76	18 01	68 11	0 93	13.390	31.20	7,440
	Checua - Lenguazaque	Cogua-Sutatausa-Guacheta	ROM	Eq + 2	13 66	9.46	26 8	60 07	0.8	13,433	31.30	7,460
		Lenguazaque -Cucunubá-Nemocón	ROM	Eq + 2	4 67	10 6	33.85	50 86	1 06	12,718	29.63	7,070
	Suesca - Albarracín		ROM	Eq + 1	3 9	10.43	33 53	52 12	0 69	12,738	29.68	7,080
Cundinamarca	Zipaquirá - Neusa	Zipaquirá-Embalse del Neusa	BCA	HR	1.04	14.42	24 33	60 21	1.38	12,993	30.27	7,220
		Embalse del Neusa-Vereda Lagunitas										
	Páramo de la Bolsa-Machetá		BCA	HR	4 42	14 21	35.7	45 67	1 04	11,309	26.35	6,280

Source: Unión Temporal CTL (2007)
Notes: VM=Volatile Matter. FC=Fixed Carbon. St= Total Sulphur. CV=Calorific Value.

Table A.4: Qualities of Coal in Colombia per Province and Areas (Continued)

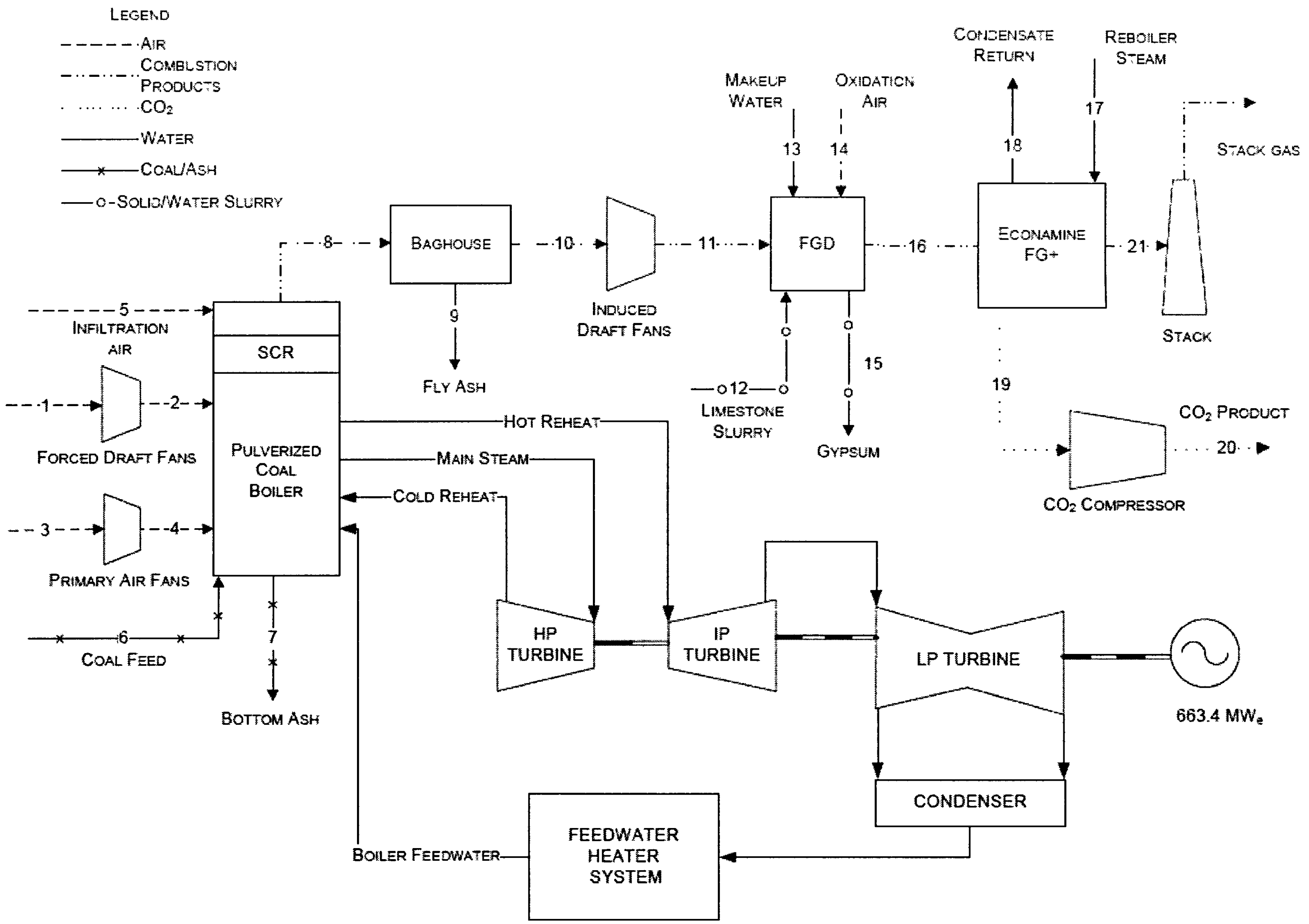
ZONE	AREA	SECTOR		BASE	MOISTURE		ASH	VM	FC	St	CV	CV	CV
						%	%	%	%	%	BTU/Lb	MJ/kg	kcal/kg
Boyacá	Checua - Lenguazaque			ROM	Eq + 2	3 56	10	25 19	61.25	0 8	13 439	31 31	7,470
Boyacá	Suesca - Albarracín			ROM	Eq + 2	4 69	12.18	33 71	49.42	1 07	12,420	28 94	6,900
Boyacá	Tunja-Paipa-Duitama			ROM	Eq. + 2	9 48	11 4	38 03	41 09	1 53	11 268	26 25	6,260
Boyacá	Sogamoso-Jericó			ROM	Eq + 2	4.29	9 57	30 19	55.96	1.23	13,099	30 52	7,280
Boyacá	Betania			BCA	HR	1 47	8.36	30 94	59 25	1	13 859	32 29	7 700
Boyacá	Úmbita-Laguna de Tota			ROM	Eq + 2	5 75	13 1	38 34	42 8	1.21	11,699	27 26	6,500
Santander	San Luis	Flanco Occidental	Térmicos	ROM	Eq. + 1	2.7	25.95	28.11	43.23	1 76	10,913	25 43	6,060
Santander	San Luis	Flanco Occidental	Coquizables	BCA	HR	1.63	7 65	33 38	57.33	1.37	13,994	32 61	7,770
Santander	San Luis	Flanco Oriental	Térmicos	BCA	HR	1.18	18 72	30 48	49.62	2.01	12,284	28 62	6,820
Santander	San Luis	Flanco Oriental	Coquizables	BCA	HR	1 18	10 09	29.05	59 67	2 15	13 893	32 37	7,720
Santander	Cimitarra Sur			BCA	HR	4 61	4 61	29 77	61.01	0 62	13,021	30 34	7,230
Santander	Capitanejo-SanMiguel			BCA	HR	6 33	7 51	19	67.16	0 93	11,782	27 45	6,550
Santander	Miranda			BCA	HR	1.81	14 47	15 13	68.59	3.46	12,803	29 83	7,110
Santander	Molagavita			BCA	HR	0.8	8.58	32.25	58 37	0 7	14,161	33 00	7,870
Santander	Páramo del Almorzadero			BCA	HR	5 18	4 71	14 23	75.88	0.75	12 889	30.03	7,160
Norte de Santander	Chitagá			ROM	Eq + 1	3.29	12 59	12 9	71.22	1.44	12,804	29 83	7,110
Norte de Santander	Pamplona-Pamplonita	Pamplonita Pamplona		ROM	Eq + 1	2.96	9 97	36 15	50.92	1.34	13,199	30 75	7,330
Norte de Santander	Herrán-Toledo	Toledo Herrán		ROM	Eq. + 1	2 31	7 46	26.99	63 24	0 83	14,120	32 90	7,840
Norte de Santander	Salazar	Norte Centro Sur		ROM	Eq. + 1	3.76	9 46	36 81	49.96	0.62	12,762	29 74	7,090
Norte de Santander	Tasajero	Este	Los Cuervos	ROM	Eq. + 1	2 84	10.17	34.82	52 18	0 85	13,326	31 05	7,400
Norte de Santander	Tasajero	Oeste	Los Cuervos	ROM	Eq + 1	2 56	7 65	33 67	56.12	0.85	13,925	32 45	7,740
Norte de Santander	Tasajero	Sur	Carbonera	ROM	Eq + 1	2 42	17 1	34 59	45 89	0 89	12,291	28 64	6,830
Norte de Santander	Zulia-Chinácota	Zulia Sur	Los Cuervos	ROM	Eq + 1	3 36	11 9	35 29	49.45	1.27	12,967	30 21	7,200
Norte de Santander	Zulia-Chinácota	Santiago	Los Cuervos	ROM	Eq + 1	2 71	5 95	30 55	60 8	0 71	14,153	32 98	7,860
Norte de Santander	Zulia-Chinácota	Santiago	Carbonera	ROM	Eq. + 1	8 33	17.06	28 67	47.73	0.62	9,911	23 09	5,510
Norte de Santander	Zulia-Chinácota	San Cayetano	Los Cuervos	ROM	Eq. + 1	2 02	12 12	26 66	59 2	1 43	13 324	31 04	7,400
Norte de Santander	Zulia-Chinácota	San Cayetano	Carbonera	ROM	Eq + 1	2.17	18.05	36 61	43.13	0.78	11,410	26 59	6,340
Norte de Santander	Zulia-Chinácota	SanPedro	Los Cuervos	ROM	Eq + 1	2 53	11 3	35 63	50.54	0.81	13,290	30 97	7,380
Norte de Santander	Zulia-Chinácota	SanPedro	Carbonera	ROM	Eq. + 1	2 69	14 88	38 49	43 94	0 83	12,436	28 98	6,910
Norte de Santander	Zulia-Chinácota	Villa del Rosario	Los Cuervos	ROM	Eq. + 1	2 74	7 5	36.7	53 06	0 7	13 588	31 66	7,550
Norte de Santander	Catatumbo	Zulia Norte-Sardinata		ROM	Eq + 1	3 67	9 18	37 57	49 59	0 95	12 602	29 36	7,000
Norte de Santander	Catatumbo	El Carmen		BCA	HR	4.31	8 64	39 17	47.88	0.95	12 316	28 70	6,840
Amazonas	Leticia			BCA	HR	10.39	30 89	36 09	22.63	3.67	6,664	15 53	3,700

Source: Unión Temporal CTL (2007)

Notes: VM=Volatile Matter. FC=Fixed Carbon. St= Total Sulphur. CV=Calorific Value.

Appendix B.

Appendix to Chapter 5



Source: U.S. DOE (2007a).

Figure B.1: Supercritical Unit with CO_2 Capture Process Flow Diagram.

Table B.1: Balance of Supercritical Coal-Fired Plant

Cooling system	Recirculating Wet Cooling Tower
Fuel and Other storage Coal	30 days
Ash	30 days
Gypsum	30 days
Limestone	30 days
Plant Distribution Voltage Motors below 1 hp	110/220 volt
Motors between 1 hp and 250 hp	480 volt
Motors between 250 hp and 5.000 hp	4.160 volt
Motors above 5,000 hp	13.800 volt
Steam and Gas Turbine generators	24.000 volt
Grid Interconnection voltage	345 kV
Water and Waste Water Makeup Water	The water supply is 50 percent from a local Publicly Owned Treatment Works (POTW) and 50 percent from groundwater. and is assumed to be in sufficient quantities to meet plant makeup requirements. Makeup for potable. process. and de-ionized (DI) water is drawn from municipal sources.
Process Wastewater	Storm water that contacts equipment surfaces is collected and treated for discharge through a permitted discharge.
Sanitary Waste Disposal	Design includes a packaged domestic sewage treatment plant with effluent discharged to the industrial wastewater treatment system. Sludge is hauled off site. Packaged plant is sized for 5.68 cubic meters per day (1.500 gallons per day)
Water Discharge	Most of the process wastewater is recycled to the cooling tower basin. Blowdown will be treated for chloride and metals, and discharged.

Source: U.S.DOE (2007a).

Table B.2: Coal-Fired Reference Power Plant Performance Summary

POWER SUMMARY (Gross Power at Generator Terminals, kWe)	
TOTAL (STEAM TURBINE) POWER, kWe	**663,445**
AUXILIARY LOAD SUMMARY, kWe (Note 1)	
Coal Handling and Conveying	490
Limestone Handling & Reagent Preparation	1,270
Pulverizers	3,990
Ash Handling	760
Primary Air Fans	1,870
Forced Draft Fans	2,380
Induced Draft Fans	10,120
SCR	70
Baghouse	100
FGD Pumps and Agitators	4,250
Econamine FG Plus Auxiliaries	21,320
CO_2 Compression	46,900
Miscellaneous Balance of Plant (Note 2)	2,000
Steam Turbine Auxiliaries	400
Condensate Pumps	630
Circulating Water Pumps	12,260
Cooling Tower Fans	6,340
Transformer Loss	2,300
TOTAL AUXILIARIES, kWe	**117,450**
NET POWER, kWe	**545,995**
Net Plant Efficiency (HHV)	27.2%
Net Plant Heat Rate (Btu/kWh)	12,534
CONDENSER COOLING DUTY, 10^6 kJ/h (10^6 Btu/h)	1,884 (1,787)
CONSUMABLES	
As-Received Coal Feed, kg/h (lb/h)	266,090 (586,627)
Limestone Sorbent Feed, kg/h (lb/h)	26,333 (58,054)
Thermal Input, kWt	2,005,660
Makeup Water, m^3/min (gpm)	46.0 (12,159)

Source: U.S. DOE (2007a).

Table B.3: Reference Coal-Fired Power Plant Green House Gases Emissions

	kg/GJ ($lb/10^6$ Btu)	Tonne/year (ton/year) 85% capacity factor	kg/MWh (lb/MWh)
SO_2	Negligible	Negligible	Negligible
NO_X	0.030 (0.070)	1,618 (1,784)	0.328 (0.722)
Particulates	0.006 (0.013)	300 (331)	0.061 (0.134)
Hg	0.49×10^{-6} (1.14×10^{-6})	0.026 (0.029)	5.3×10^{-6} (11.8×10^{-6})
CO_2	8.7 (20)	468,000 (516,000)	95 (209)
CO_2[1]			115 (254)

[1] CO_2 emissions based on net power instead of gross power

Source: U.S. DOE (2007a).

Table B.4: Reference Coal-Fired Power Plant Water Balance

Water Use	Water Demand, m^3/min (gpm)	Internal Recycle, m^3/min (gpm)	Raw Water Makeup, m^3/min (gpm)
FGD Makeup	2.9 (779)	0	2.9 (779)
BFW Makeup	0.4 (105)	0	0.4 (105)
Cooling Tower Makeup	41.2 (10,885)	5.0 (1,324)	36.2 (9,561)
Total	**44.5 (11,769)**	**5.0 (1,324)**	**39.5 (10,444)**

Source: U.S. DOE (2007a).

Table B.5: Reference Coal-Fired Power Plant Total Cost Summary

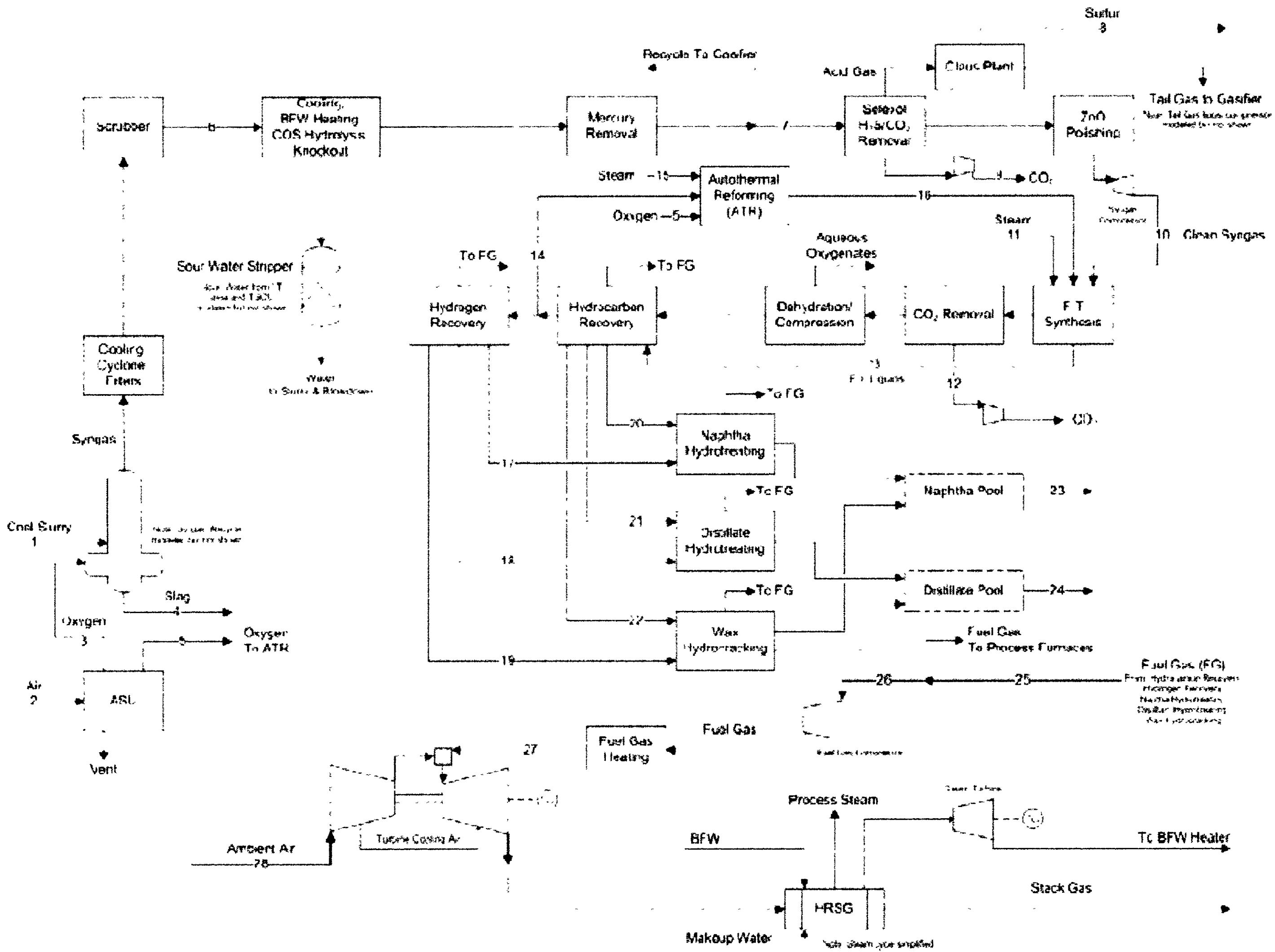
Client: USDOE/NETL — **Report Date:** 09-May-07
Project: Bituminous Baseline Study

TOTAL PLANT COST SUMMARY

Case: Case 12 - Supercritical PC w/ CO2
Plant Size: 546.0 MW,net — **Estimate Type:** Conceptual — **Cost Base (Dec)** 2006 ($x1000)

Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Sales Tax	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $	TOTAL PLANT COST $/kW
1	COAL & SORBENT HANDLING	$19,316	$5,215	$11,691	$0	$0	$36,222	$3,246	$0	$5,920	$45,389	$83
2	COAL & SORBENT PREP & FEED	$13,126	$758	$3,326	$0	$0	$17,210	$1,508	$0	$2,808	$21,527	$39
3	FEEDWATER & MISC BOP SYSTEMS	$54,477	$0	$25,648	$0	$0	$80,126	$7,317	$0	$14,428	$101,870	$187
4	PC BOILER											
4.1	PC Boiler & Accessories	$190,969	$0	$107,678	$0	$0	$298,647	$28,927	$0	$32,757	$360,332	$660
4 2	SCR (w/4 1)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.3	Open	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
4.4-4 9	Boiler BoP (w/ ID Fans)	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 4	**$190,969**	**$0**	**$107,678**	**$0**	**$0**	**$298,647**	**$28,927**	**$0**	**$32,757**	**$360,332**	**$660**
5	FLUE GAS CLEANUP	$101,747	$0	$34,963	$0	$0	$136,710	$12,990	$0	$14,970	$164,670	$302
5B	CO_2 REMOVAL & COMPRESSION	$229,832	$0	$69,851	$0	$0	$299,683	$28,443	$52,879	$76,201	$457,207	$837
6	COMBUSTION TURBINE/ACCESSORIES											
6.1	Combustion Turbine Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
6.2-6 9	Combustion Turbine Other	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
	SUBTOTAL 6	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
7	HRSG, DUCTING & STACK											
7 1	Heat Recovery Steam Generator	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
7 2-7.9	HRSG Accessories, Ductwork and Stack	$17,889	$981	$12,221	$0	$0	$31,091	$2,840	$0	$4,457	$38,388	$70
	SUBTOTAL 7	**$17,889**	**$981**	**$12,221**	**$0**	**$0**	**$31,091**	**$2,840**	**$0**	**$4,457**	**$38,388**	**$70**
8	STEAM TURBINE GENERATOR											
8.1	Steam TG & Accessories	$53,763	$0	$7,192	$0	$0	$60,956	$5,836	$0	$6,679	$73,471	$135
8.2-8.9	Turbine Plant Auxiliaries and Steam Piping	$26,923	$1,148	$14,942	$0	$0	$43,013	$3,724	$0	$6,698	$53,436	$98
	SUBTOTAL 8	**$80,687**	**$1,148**	**$22,134**	**$0**	**$0**	**$103,969**	**$9,561**	**$0**	**$13,377**	**$126,907**	**$232**
9	COOLING WATER SYSTEM	$21,479	$11,200	$19,881	$0	$0	$52,559	$4,900	$0	$7,796	$65,255	$120
10	ASH/SPENT SORBENT HANDLING SYS	$5,154	$162	$6,854	$0	$0	$12,169	$1,158	$0	$1,371	$14,699	$27
11	ACCESSORY ELECTRIC PLANT	$20,196	$10,240	$29,287	$0	$0	$59,723	$5,331	$0	$8,288	$73,343	$134
12	INSTRUMENTATION & CONTROL	$9,195	$0	$9,662	$0	$0	$18,857	$1,726	$943	$2,648	$24,174	$44
13	IMPROVEMENTS TO SITE	$3,162	$1,818	$6,421	$0	$0	$11,402	$1,120	$0	$2,504	$15,026	$28
14	BUILDINGS & STRUCTURES	$0	$23,760	$22,735	$0	$0	$46,495	$4,189	$0	$7,603	$58,287	$107
	TOTAL COST	**$767,230**	**$55,282**	**$382,352**	**$0**	**$0**	**$1,204,865**	**$113,256**	**$53,822**	**$195,130**	**$1,567,073**	**$2,870**

Source: U.S. DOE (2007a).



Source: U.S. DOE (2007b).

Figure B.2: Coal to Liquid Process Block Flow Diagram.

Table B.6: Coal to Liquids Reference Plant Performance Summary

Parameter	Value
Naphtha Production, bbl/day	22,173
Diesel Production, bbl/day	27,819
Net Plant Power, MW_e	124.3
Coal Feed Flow Rate, tons/day	24,533
Elemental Sulfur Production, tons/day	612
Carbon Dioxide Capture, tons/day	32,481

Source: U.S. DOE (2007b).

Table B.7: Balance of Coal to Liquids Reference Plant

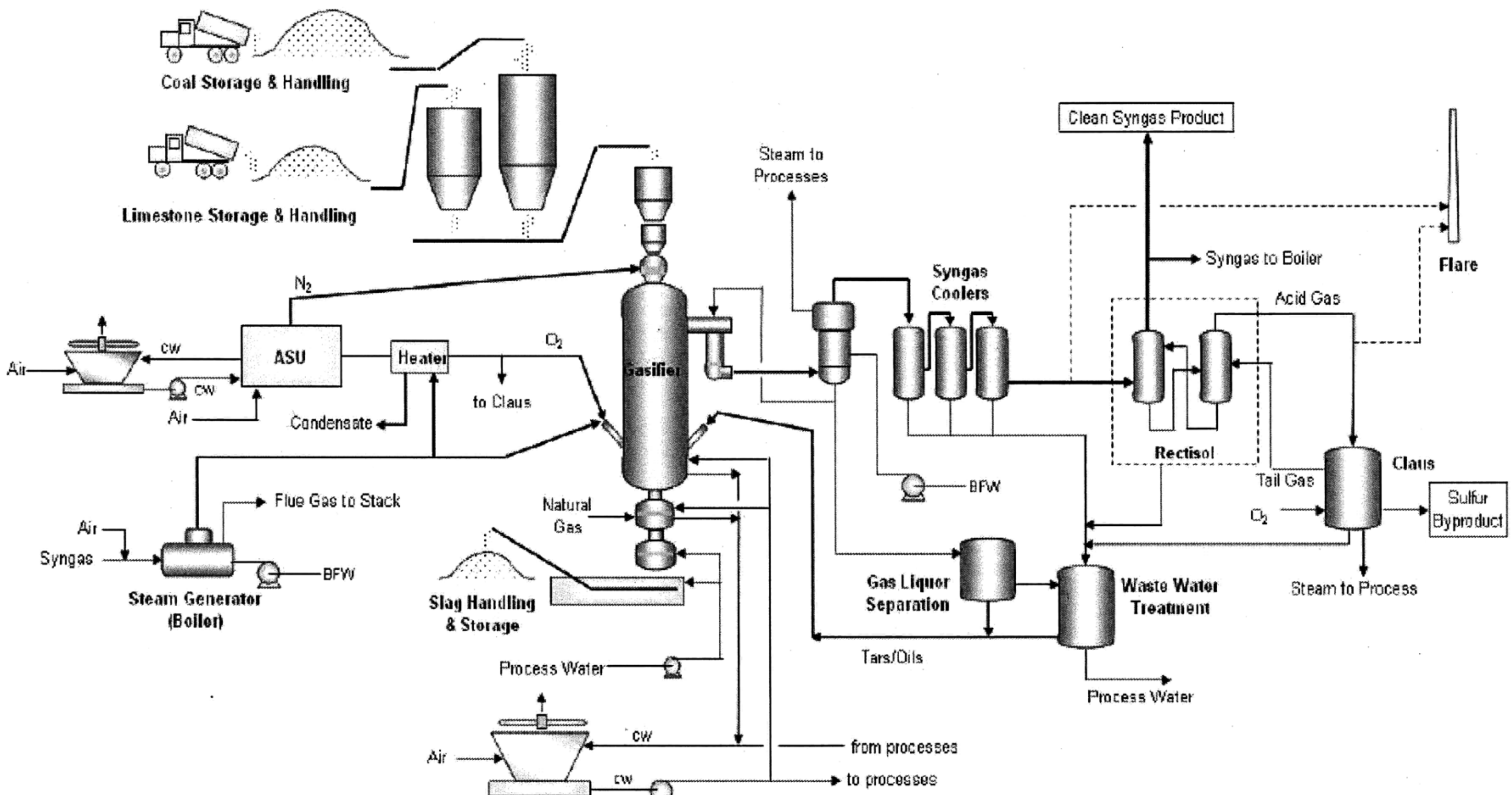
Cooling system	Recirculating, evaporative cooling tower or hybrid air/water cooling tower.
Fuel and Other Storage	
Coal	30 days
Slag	30 days
Sulfur	30 days
Plant Distribution Voltage	
Motors below 1 hp	110/220 volt
Motors 250 hp and below	480 volt
Motors above 250 hp	4,160 volt
Motors above 5,000 hp	13,800 volt
Steam and gas tubine generators	24,000 volt
Grid interconnection voltage	345 kV
Water and Waste Water	
Makeup water	Process water is available from the river or from existing or new wells at a flow rate of 1,500 gpm.
Feedwater	Treatment of the water supply is included and will produce boiler feed quality water for the IGCC plant.
Process wastewater	Water associated with gasification activity and storm water that contacts equipment surfaces will be collected and treated for discharge through a permitted discharge facility
Sanitary waste disposal	Design will include a packaged domestic sewage treatment plant with effluent discharged to the industrial wastewater treatment system. Sludge will be hauled off site.
Water discharge	Most of the wastewater will be recycled for plant needs Blowdown will be treated for chloride and metals, and discharged.
Solid waste	Gasifier slag is assumed to be a solid waste that is classified as non-hazardous An offsite waste disposal site is assumed to have the capacity to accept waste generated throughout the life of the facility. Solid waste sent to disposal is at an assumed nominal fee per ton, even if the waste is hauled back to the mine. Solid waste that can be recycled or reused is assumed to have a zero cost

Source: U.S. DOE (2007b).

Table B.8: Coal to Liquids Reference Plant Capital Cost Summary

	Client:	DEPARTMENT OF ENERGY							Report Date:	10-Dec-08
	Project:	NETL Coal To Liquids Study - Illinois								
		Activity 1			TOTAL PLANT COST SUMMARY					
	Case:	E-Gas Design for Fischer-Tropsch (No Refinery, No Sequestration)								
	Plant Size:	125.254 MW,net		Estimate Type:	Conceptual			Cost Base (July)	2006 ; $x1000	
		50,002 FT Liquids bbl/day								
Acct No.	Item/Description	Equipment Cost	Material Cost	Labor Direct	Labor Indirect	Bare Erected Cost $	Eng'g CM H.O.& Fee	Contingencies Process	Contingencies Project	TOTAL PLANT COST $
1	COAL & SORBENT HANDLING	40,655	3,404	35,203	2,464	**86,727**	6,938		23,416	**117,081**
2	COAL-WATER SLURRY PREP & FEED	62,767	13,721	51,844	3,629	**131,962**	10,557		35,630	**178,148**
3	FEEDWATER & MISC BOP SYSTEMS	12,310	11,530	12,929	905	**37,674**	3,014		10,172	**50,859**
4	GASIFIER & ACCESSORIES									
4.1	Gasifier & Auxiliaries	270,951	128,128	223,895	15,673	**638,647**	51,092		172,435	**862,173**
4.2	Syngas Cooling	w/4.1	w/4.1	w/4.1						
4.3	ASU/Oxidant Compression	287,187		w/equip.		**287,187**	22,975		77,540	**387,702**
4.4-4.9	Other Gasification Equipment	46,865	57,900	65,414	4,579	**174,757**	13,981		47,184	**235,922**
	Subtotal 4	605,002	186,028	289,309	20,252	**1,100,591**	88,247		297,159	**1,485,797**
5A	GAS CLEANUP	164,720	18,909	169,318	11,852	364,800	29,184		98,496	**492,480**
5b	FISCHER-TROPSCH SYSTEMS	326,877	48,364	39,571	2,770	417,582	33,407	112,747	140,934	**704,669**
6	COMBUSTION TURBINE GENERATOR									
6.1	Combustion Turbine Generator	69,575		2,445	171	**72,191**	5,775		19,492	**97,458**
6.2-6.9	Combustion Turbine/Generator Accessories		437	387	27	**851**	68		230	**1,149**
	Subtotal 6	69,575	437	2,832	198	**73,042**	5,843		19,721	**98,607**
7	HRSG, DUCTING & STACK									
7.1	Heat Recovery Steam Generator	20,035		2,445	171	**22,651**	1,812		6,116	**30,579**
7.2-7.9	HRSG Accessories, Ductwork and Stack	1,942	1,320	1,558	109	**4,929**	394		1,331	**6,655**
	Subtotal 7	21,977	1,320	4,003	280	**27,581**	2,206		7,447	**37,234**
8	STEAM TURBINE GENERATOR									
8.1	Steam TG & Accessories	45,258		6,037	423	51,718	4,137		13,964	69,819
8.2-8.9	Turbine Plant Auxiliaries & Steam Piping	12,080	1,195	9,025	632	**22,933**	1,835		6,192	**30,959**
	Subtotal 8	57,339	1,195	15,062	1,054	**74,651**	5,972		20,156	**100,778**
9	COOLING WATER SYSTEM	13,603	9,129	12,852	900	**36,484**	2,919		9,851	**49,254**
10	ASH/SPENT SORBENT HANDLING SYS	47,228	26,435	44,694	3,129	**121,486**	9,719		32,801	**164,006**
11	ACCESSORY ELECTRIC PLANT	12,858	6,162	15,567	1,090	**35,676**	2,854		9,633	**48,163**
12	INSTRUMENTATION & CONTROL	19,899	3,238	16,063	1,124	**40,324**	3,226		10,888	**54,438**
13	IMPROVEMENTS TO SITE	6,302	3,998	14,961	1,047	**26,308**	2,105		7,103	**35,515**
14	BUILDINGS & STRUCTURES		8,918	14,464	1,012	**24,395**	1,952		6,587	**32,933**
	TOTAL COST	**$1,461,113**	**$347,788**	**$738,673**	**$51,707**	**$2,599,281**	**$207,943**	**$112,747**	**$729,993**	**$3,649,964**

Source: U.S. DOE (2007b).



Source: U.S. DOE (2007c).

Figure B.3: Major Systems Comprising the Syngas Production Reference Plant.

Table B.9: Syngas Reference Plant Estimated Performance Summary

Production Figures (average)	
Total Syngas Flow, lb/hr (scfh x 10^6)	158,700 (2.96)
Syngas Higher Heating Value, Btu/lb (Btu/scf)[a]	6,291 (337)
Syngas Lower Heating Value, Btu/lb (Btu/scf)	5,894 (316)
Exported Syngas Flow lb/hr (scfh x 10^6)[b]	151,400 (2.54)
Exported Syngas Energy, MMBtu/hr (HHV)	952
Elemental Sulfur Product, lb/hr	2,999
Slag, lb/hr	13,787
Consumption Figures (average)	
Coal Thermal Input , MMBtu/hr (HHV)[c]	1,118
Coal Feed, lb/hr	95,409
Flux (Limestone) Feed, lb/hr	2,442
Oxygen to Gasifier and Claus Furnace, lb/hr	48,623
Nitrogen for Feed Lock Purge, lb/hr	4,409
Steam to Gasifier[d], lb/hr	29,158
Cooling Makeup Water (Syngas Plant), lb/hr	55,440
Process Makeup Water[e], lb/hr	61,632
Methanol, lb/hr	30
Natural Gas to Slag Tap (ring) burner, lb/hr	140
Aux. Electric Power (Syngas Plant), kWe	5,140
ASU Electric Power, kWe	9,700
ASU Cooling Makeup Water, lb/hr	27,100
Plant Equivalent Efficiency	
Fuel and Power Energy Input[f], MMBtu/hr	1275
Energy in Exported Syngas Product, MMBtu/hr	952
Plant Net Thermal Efficiency[g], %	74.7
Emissions	
Gasification Plant Syngas Fired Boiler	
SO_2 , lb/MMBtu	< 0.003
NOx, lb/MMBtu[h]	< 0.1
Hg, lb/trillionBtu[i]	< 0.001
CO_2, lb/MMBtu	< 225

Note a: Standard Conditions: 14.7 psia, 60°F
Note b: Total syngas from cleanup system minus syngas used in the gasification system processes
Note c: Based on Illinois #6 coal with HHV of 11,714 Btu/lb
Note d: Generated in a fired boiler using tailgas from the processes and portion of syngas produced
Note e: A detailed optimization of water recycling in the plant was not performed. An optimization study may reduce the process water makeup requirement.
Note f: Coal energy plus natural gas energy (to ring burner) plus purchased aux. power and ASU power expressed as thermal energy to utility power generation plant with HHV efficiency of 32.8%.
Note g: Defined in accordance with DOE Quality Guidelines for Energy System Studies as energy in exported syngas product divided by plant energy input as defined in Note e.
Note h: Without post-combustion controls (e.g. SCR).
Note i: Based on Hg content in coal of < 0.12 ppm and 90% or higher removal efficiency.

Source: U.S. DOE (2007c).

Table B.10: Syngas Reference Plant Capital Cost Summary

CODE	ITEM	EQUIPMENT	MATERIAL	LABOR	TOTAL	COMMENTS
						22,848 MMBtu/day
1.0	Coal & Sorbent Handling	$ 913,985	$ 111,057	$ 404,090	$ 1,429,132	Coal & Flux Receiving & Reclaim
2.0	Coal & Sorbent Prep & Feed	$ 1,628,788	$ 128,284	$ 600,765	$ 2,357,837	Coal & Flux Storage & Feed to Gasifier
3.0	Misc. BOP Systems	$ 731,374	$ 444,117	$ 444,398	$ 1,619,890	
4.0	Gasifier & Accessories	$ 18,132,336	$ 642,216	$ 11,367,299	$ 30,141,850	Gasifier, Gas Cooling, Slag Quench, Tar Separation
4.0	ASU Plant	$ -	$ -	$ -	$ -	Off-Site (see O&M)
5.0	Gas Cleanup	$ 19,384,063	$ 4,918,095	$ 9,712,246	$ 34,014,404	Rectisol, Claus & Gas Liquor Treating
5.0	CO2 Removal & Compression	$ -	$ -	$ -	$ -	
6.0	Combustion Turbine Plant	$ -	$ -	$ -	$ -	
7.0	HRSG, Ducting & Stack	$ -	$ -	$ -	$ -	
8.0	Steam Turbine Generator	$ -	$ 186,871	$ 113,187	$ 300,058	Steam Piping System
9.0	Cooling Water System	$ 928,242	$ 575,636	$ 479,993	$ 1,983,871	Cooling Tower Cooling & Component Cooling
10.0	Ash Handling System	$ 804,136	$ 294,871	$ 312,194	$ 1,411,202	Slag Conveyor & Truck Feed
11.0	Accessory Electric Plant	$ 2,189,662	$ 1,053,437	$ 2,019,357	$ 5,262,456	
12.0	Instrumentation & Control	$ 2,445,502	$ 276,391	$ 951,747	$ 3,673,640	
13.0	Improvements to Site	$ 217,145	$ 255,977	$ 568,091	$ 1,041,213	
14.0	Buildings & Structures	$ -	$ 983,697	$ 628,015	$ 1,611,712	
	TOTAL FIELD COST	$ 47,375,232	$ 9,870,648	$ 27,601,383	$ 84,847,263	
	PROFESSIONAL SERVICES:	$ 8,484,700	$ -	$ -	$ 8,484,700	Includes Engineering, Design & CM
	OTHER COSTS (LESS Escalation)	$ 4,500,000	$ -	$ 200,000	$ 4,700,000	Freight, Heavy Haul, Startup Spares & Insurances
	ESCALATION	$ -	$ -	$ -	$ -	Excluded
						$/MMBtu/day
	TOTAL (w/o CONTINGENCY)	$ 60,359,932	$ 9,870,648	$ 27,801,383	$ 98,031,963	4,290
	CONTINGENCY				$ 20,685,037	
						$/MMBtu/day
	TOTAL				$ 118,717,000	5,200

Source: U.S. DOE (2007c).

Table B.11: Simplified Input-Output Colombian Matrix

Millions of Pesos

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Agriculture, Forestry, Fishing and Hunting	3,102,465	0	253	47,413	36	20,919,145	402,888	601,085	15,113	0	0	24,449	149,794	2,198
2 Coal	136	155,898	0	57,948	1,543	30,898	9,118	731	59,108	171	2,691	18,706	2,426	49,299
3 Crude Oil and Natural Gas	0	0	1,701,561	0	0	0	0	0	0	0	6,864,300	0	0	0
4 Metalic Minerals	0	0	0	554	0	0	0	0	0	0	0	10,028	0	23,764
5 Non-Metalic Minerals	8,878	1,153	31,031	15,072	14,172	21,604	3,053	0	124	0	0	167,596	990	750,482
6 Food Production	2,504,030	0	0	0	0	8,694,739	302,235	5,871	31,827	131	1,713	371,367	2,833	2,755
7 Textile Production and Apparel Manufacturing	318,091	5,793	18,723	591	169	60,841	5,941,833	27,718	137,898	32,648	0	60,258	132,231	11,849
8 Wood Products	150,871	0	401	0	1,025	10,243	4,945	352,402	121,309	287	0	4,392	14,239	12,475
9 Paper and Carton Products	178,984	6,960	316	920	2,949	605,802	128,768	14,738	1,422,690	1,474,563	18,108	234,770	114,256	148,446
10 Printing and Editing	39,741	1,656	672	0	1,206	800,287	122,117	2,682	84,122	745,275	10,402	387,888	49,638	50,679
11 Oil Refining Products, Fuels	517,300	736,835	0	500,660	52,421	594,443	183,027	22,247	152,081	52,503	450,166	533,002	94,005	743,789
12 Chemical Substances and Products	3,787,094	149,271	7,351	38,034	91,729	842,534	1,810,897	55,843	559,937	206,452	227,208	7,373,386	3,109,062	412,065
13 Rubber and Plastic Products	209,543	126,924	86,328	21,086	848	1,556,683	340,557	19,282	267,735	96,421	53,425	1,011,581	322,344	156,082
14 Non-Metalic Minerals Products	68,118	0	1,343	11,853	1,596	342,573	5,065	3,946	3,454	374	82	261,435	81,829	897,549
15 Basic Metallurgic Products (Iron, Steel, Except Machinery)	346,665	0	45,276	28,007	2,361	841,530	224,466	102,143	115,013	52,509	43,048	341,287	119,045	268,589
16 Machinery and Equipment (Transportation Machinery)	258,975	343,147	259,739	180,591	66,587	672,095	257,456	20,621	133,356	123,230	61,658	424,281	169,620	306,282
17 Furniture	0	0	0	0	0	0	0	174	173	0	0	0	0	0
18 Other Manufactured Goods	404	0	0	0	0	977	35,926	119	0	5,927	713	12,702	1,767	336
19 Waste Products	0	0	0	0	0	111,964	10,232	5,788	579,778	185	1,078	85,035	38,678	75,225
20 Electric Power	111,225	76,519	35,529	126,819	16,959	459,890	264,104	37,638	101,846	34,970	8,260	215,222	197,202	243,686
21 Gas Supply	492	0	0	32,352	0	250,804	37,549	3,882	45,352	625	464	134,462	8,690	177,617
22 Water Supply	16,873	1,204	3,039	473	1,599	52,588	20,488	4,737	2,968	6,196	1,951	12,399	6,724	6,635
23 Building Construction and Machinery Rental	2,197	17,051	0	0	0	46,027	7,474	1,076	1,044	1,278	1,155	5,542	2,679	525
24 Works and Facilities Construction	134,531	392,015	14,849	0	0	0	0	0	0	0	0	0	0	0
25 Commerce	0					0	0							
26 Transportation (Road, Water, Air)	509,599	389,653	1,128,390	98,473	4,516	1,352,744	362,848	48,877	167,895	153,169	208,957	605,208	189,493	365,555
27 Additional Transportation Services (Storage, Handling)	47	910,144	0	0	11,251	2,338	5,473	2,036	212	324	0	383	121	4,149
28 Services to Companies (Finance, RE,Health)	1,127,445	570,940	823,983	243,535	47,287	3,562,599	1,346,739	92,629	488,876	605,446	305,203	2,231,632	653,058	837,350
Wages and Salaries	7,948,491	642,421	295,784	188,138	379,692	4,485,176	2,890,261	447,104	644,333	562,706	438,481	2,165,744	1,169,413	984,903
Value Added	33,147,320	5,049,524	16,752,346	3,544,554	1,770,946	14,831,865	6,763,764	832,144	1,883,479	2,345,211	7,143,098	6,343,739	2,196,915	4,081,328
Total Intermediary Inputs	13,393,704	3,885,163	4,158,784	1,404,381	318,254	41,833,348	11,827,258	1,426,265	4,491,911	3,592,684	8,260,582	14,527,011	5,460,724	5,547,381
Total Outlays	46,541,024	8,934,687	20,911,130	4,948,935	2,089,200	56,665,213	18,591,022	2,258,409	6,375,390	5,937,895	15,403,680	20,870,750	7,657,639	9,628,709

Sector	15	16	17	18	19	20	21	22	23	24	25	26	27	28	Household Consump.
1 Agriculture, Forestry, Fishing and Hunting	1,452	460	70,393	13,303	0	0	0	0	0	52,921	0	0	0	1,286,696	19,994,737
2 Coal	31,901	2,938	178	256	0	253,085	0	0	0	0	0	0	0	0	1,165
3 Crude Oil and Natural Gas	0	0	0	0	0	554,702	596,113	0	0	0	0	0	0	0	0
4 Metalic Minerals	2,296,447	13,019	0	6,158	0	0	0	0	0	0	0	0	0	1,419	0
5 Non-Metalic Minerals	9,627	5,857	339	81,794	0	0	0	0	383,082	724,668	0	0	0	11,578	0
6 Food Production	169	398	0	10,484	0	0	0	0	0	0	7,932	9,447	2,058	3,967,662	56,215,117
7 Textile Production and Apparel Manufacturing	4,044	82,675	200,458	38,609	956	4,454	1,376	1,922	62,294	0	1,751	4,995	8,606	1,181,823	13,457,124
8 Wood Products	34,273	45,757	479,205	99,148	0	0	0	0	910,293	527,444	0	0	0	76,794	0
9 Paper and Carton Products	74,450	82,769	8,588	57,718	133	0	0	21,254	19,203	4,603	540,750	17,081	125,874	2,287,665	1,789,912
10 Printing and Editing	84,646	115,259	10,909	23,230	0	32,280	15,060	7,440	0	1,414	1,251,259	114,568	87,765	2,758,814	2,259,791
11 Oil Refining Products, Fuels	261,224	120,763	20,238	243,414	29,253	14,944	105,254	9,216	23,126	110,949	319,886	6,797,773	136,833	2,145,675	3,686,442
12 Chemical Substances and Products	359,554	591,022	225,419	172,881	0	16,263	13,447	3,922	892,006	117,479	171,137	5,053	20,728	4,988,317	8,882,509
13 Rubber and Plastic Products	189,581	376,457	105,818	65,764	407	0	3,745	6,902	1,600,410	87,970	1,537,469	1,123,247	4,258	1,426,553	409,320
14 Non-Metalic Minerals Products	66,110	153,570	20,486	4,004	0	0	0	0	4,625,864	3,246,628	0	0	0	104,593	610,078
15 Basic Metallurgic Products (Iron, Steel, Except Machinery)	5,980,833	2,082,972	469,426	236,655	0	4,935	35,675	31,937	3,416,589	5,516,686	135,214	34,269	52,695	2,174,691	502,164
16 Machinery and Equipment (Transportation Machinery)	283,477	4,415,085	35,364	34,865	1,691	832,372	410,239	49,395	570,235	461,121	588,520	99,386	103,632	7,879,422	11,851,167
17 Furniture	1	2,114	65,618	269	0	0	0	0	291,023	0	0	4,979	0	99,602	2,415,506
18 Other Manufactured Goods	55	191	573	57,034	0	1,646	643	912	12,171	3,091	42,993	8,817	3,404	459,651	4,176,580
19 Waste Products	383,398	42,151	6,574	3,450	0	0	0	0	0	0	3	0	0	0	0
20 Electric Power	356,112	86,588	27,164	26,037	1,759	5,592,886	23,517	45,189	0	1,809	797,176	31,199	103,834	2,472,180	4,204,060
21 Gas Supply	60,027	9,704	2,067	1,894	0	0	55,866	0	0	0	69,813	0	2,368	980,843	1,930,988
22 Water Supply	8,522	13,285	4,754	6,073	74	2,206	1,049	1,316	4,792	6,016	29,478	3,797	3,523	268,157	1,323,759
23 Building Construction and Machinery Rental	3,999	5,803	1,003	431	0	3,835	0	0	151,466	0	11,065	2,183	35,038	1,488,762	914,865
24 Works and Facilities Construction	0	0	0	0	0	173,315	5,980	14,744	0	1,803,649	0	12,471	107,676	146,838	0
25 Commerce		0										0		0	0
26 Transportation (Road, Water, Air)	377,334	299,993	46,410	49,001	41	42,368	14,268	6,631	3,398	0	2,555,372	156,510	117,736	2,752,002	17,772,747
27 Additional Transportation Services (Storage, Handling)	8,536	296	1,843	1,295	13,133	0	10,424	0	0	0	322,567	3,313,548	41,380	223,822	778,703
28 Services to Companies (Finance, RE,Health)	937,147	1,110,149	178,176	227,561	2,403	1,132,335	826,848	389,330	1,003,097	940,873	9,969,852	5,651,109	1,997,307	46,698,697	84,392,626
Wages and Salaries	1,174,380	1,560,816	378,621	247,549	92,180	1,543,889	209,007	343,397	2,738,528	1,519,442	18,388,445	2,557,802	1,299,348	61,909,752	2,663,710
Value Added	5,812,824	4,857,747	1,075,260	1,314,319	1,116,014	8,018,612	1,278,788	1,474,236	14,362,761	11,212,718	37,724,246	14,900,874	1,982,359	140,077,019	2,663,710
Total Intermediary Inputs	11,812,919	9,659,275	1,981,003	1,461,328	49,850	8,661,626	2,119,504	590,110	13,969,049	13,607,321	18,352,237	17,390,432	2,954,715	85,882,256	237,569,360
Total Outlays	17,625,743	14,517,022	3,056,263	2,775,647	1,165,864	16,680,238	3,398,292	2,064,346	28,331,810	24,820,039	56,076,483	32,291,306	4,937,074	225,959,275	240,233,070

Source: DANE (2008)

Table B.12: Leontief Matrix from the Simplified Input-Output Colombian Matrix

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	House-hold
1 Agriculture, Forestry, Fishing and Hunting	0.9333	0.0000	0.0000	-0.0096	0.0000	-0.3692	-0.0217	-0.2662	-0.0024	0.0000	0.0000	-0.0012	-0.0196	-0.0002	-0.0001	0.0000	-0.0230	-0.0048	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0021	0.0000	0.0000	0.0000	-0.0057	-0.0832
2 Coal	0.0000	0.9826	0.0000	-0.0117	-0.0007	-0.0005	-0.0005	-0.0003	-0.0093	0.0000	-0.1396	-0.0009	-0.0003	-0.0051	-0.0018	-0.0002	-0.0001	-0.0001	0.0000	-0.0152	-0.0440	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3 Crude Oil and Natural Gas	0.0000	0.0000	0.9186	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.3062	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0333	-0.1314	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4 Metallic Minerals	0.0000	0.0000	0.0000	0.9999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0005	0.0000	-0.0025	-0.1303	-0.0009	0.0000	-0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5 Non-Metallic Minerals	-0.0002	-0.0001	-0.0015	-0.0030	0.9932	-0.0004	-0.0002	0.0000	0.0000	0.0000	0.0000	-0.0080	-0.0001	-0.0779	-0.0005	-0.0004	-0.0001	-0.0295	0.0000	0.0000	0.0000	0.0000	-0.0135	-0.0292	0.0000	0.0000	0.0000	-0.0001	0.0000
6 Food Production	-0.0538	0.0000	0.0000	0.0000	0.0000	0.8466	-0.0163	-0.0026	-0.0050	0.0000	-0.0001	-0.0178	-0.0004	-0.0003	0.0000	0.0000	0.0000	-0.0038	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	-0.0003	-0.0004	-0.0176	-0.2340
7 Textile Production and Apparel Manufacturing	-0.0068	-0.0006	-0.0009	-0.0001	-0.0001	-0.0011	0.6804	-0.0123	-0.0216	-0.0055	0.0000	-0.0029	-0.0173	-0.0012	-0.0002	-0.0057	-0.0656	-0.0139	-0.0008	-0.0003	-0.0004	-0.0009	-0.0022	0.0000	0.0000	-0.0002	-0.0017	-0.0052	-0.0560
8 Wood Products	-0.0032	0.0000	0.0000	0.0000	-0.0005	-0.0002	-0.0003	0.8440	-0.0190	0.0000	0.0000	-0.0002	-0.0019	-0.0013	-0.0019	-0.0032	-0.1568	-0.0357	0.0000	0.0000	0.0000	0.0000	-0.0321	-0.0213	0.0000	0.0000	0.0000	-0.0003	0.0000
9 Paper and Carton Products	-0.0038	-0.0008	0.0000	-0.0002	-0.0014	-0.0107	-0.0069	-0.0065	0.7768	-0.2483	-0.0012	-0.0112	-0.0149	-0.0154	-0.0042	-0.0057	-0.0028	-0.0208	-0.0001	0.0000	0.0000	-0.0103	-0.0007	-0.0002	-0.0096	-0.0005	-0.0255	-0.0101	-0.0075
10 Printing and Editing	-0.0009	-0.0002	0.0000	0.0000	-0.0006	-0.0141	-0.0066	-0.0012	-0.0132	0.8745	-0.0007	-0.0186	-0.0065	-0.0053	-0.0048	-0.0079	-0.0036	-0.0084	0.0000	-0.0019	-0.0044	-0.0036	0.0000	-0.0001	-0.0223	-0.0035	-0.0178	-0.0122	-0.0094
11 Oil Refining Products, Fuels	-0.0111	-0.0825	0.0000	-0.1012	-0.0251	-0.0105	-0.0098	-0.0099	-0.0239	-0.0088	0.9708	-0.0255	-0.0123	-0.0772	-0.0148	-0.0083	-0.0066	-0.0877	-0.0251	-0.0009	-0.0310	-0.0045	-0.0008	-0.0045	-0.0057	-0.2105	-0.0277	-0.0095	-0.0153
12 Chemical Substances and Products	-0.0814	-0.0167	-0.0004	-0.0077	-0.0439	-0.0149	-0.0974	-0.0247	-0.0878	-0.0348	-0.0148	0.6467	-0.4060	-0.0428	-0.0204	-0.0407	-0.0738	-0.0623	0.0000	-0.0010	-0.0040	-0.0019	-0.0315	-0.0047	-0.0031	-0.0002	-0.0042	-0.0221	-0.0370
13 Rubber and Plastic Products	-0.0045	-0.0142	-0.0041	-0.0043	-0.0004	-0.0275	-0.0183	-0.0085	-0.0420	-0.0162	-0.0035	-0.0485	0.9579	-0.0162	-0.0108	-0.0259	-0.0346	-0.0237	-0.0003	0.0000	-0.0011	-0.0033	-0.0565	-0.0035	-0.0274	-0.0348	-0.0009	-0.0063	-0.0017
14 Non-Metallic Minerals Products	-0.0015	0.0000	-0.0001	-0.0024	-0.0008	-0.0060	-0.0003	-0.0017	-0.0005	-0.0001	0.0000	-0.0125	-0.0107	0.9068	-0.0038	-0.0106	-0.0067	-0.0014	0.0000	0.0000	0.0000	0.0000	-0.1633	-0.1308	0.0000	0.0000	0.0000	-0.0005	-0.0025
15 Basic Metallurgic Products (Iron, Steel, Except Machinery)	-0.0074	0.0000	-0.0022	-0.0057	-0.0011	-0.0149	-0.0121	-0.0452	-0.0180	-0.0088	-0.0028	-0.0164	-0.0155	-0.0279	0.6607	-0.1435	-0.1536	-0.0853	0.0000	-0.0003	-0.0105	-0.0155	-0.1206	-0.2223	-0.0024	-0.0011	-0.0107	-0.0096	-0.0021
16 Machinery and Equipment (Transportation Machinery)	-0.0056	-0.0394	-0.0124	-0.0365	-0.0319	-0.0119	-0.0138	-0.0091	-0.0209	-0.0208	-0.0040	-0.0203	-0.0222	-0.0318	-0.0161	0.6959	-0.0116	-0.0126	-0.0015	-0.0499	-0.1207	-0.0239	-0.0201	-0.0186	-0.0105	-0.0031	-0.0210	-0.0349	-0.0493
17 Furniture	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0001	0.9785	-0.0001	0.0000	0.0000	0.0000	0.0000	-0.0103	0.0000	0.0000	-0.0002	0.0000	-0.0004	-0.0101
18 Other Manufactured Goods	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0019	-0.0001	0.0000	-0.0010	0.0000	-0.0006	-0.0002	0.0000	0.0000	0.0000	-0.0002	0.9795	0.0000	-0.0001	-0.0002	-0.0004	-0.0004	-0.0001	-0.0008	-0.0003	-0.0007	-0.0020	-0.0174
19 Waste Products	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0020	-0.0006	-0.0026	-0.0969	0.0000	-0.0001	-0.0041	-0.0051	-0.0078	-0.0218	-0.0029	-0.0022	-0.0012	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
20 Electric Power	-0.0024	-0.0086	-0.0017	-0.0256	-0.0081	-0.0081	-0.0142	-0.0167	-0.0160	-0.0059	-0.0005	-0.0103	-0.0258	-0.0253	-0.0202	-0.0060	-0.0089	-0.0094	-0.0015	0.6647	-0.0069	-0.0219	0.0000	-0.0001	-0.0142	-0.0010	-0.0210	-0.0109	-0.0175
21 Gas Supply	0.0000	0.0000	0.0000	-0.0065	0.0000	-0.0044	-0.0020	-0.0017	-0.0071	-0.0001	0.0000	-0.0064	-0.0011	-0.0184	-0.0034	-0.0007	-0.0007	-0.0007	0.0000	0.0000	0.9836	0.0000	0.0000	0.0000	-0.0012	0.0000	-0.0005	-0.0043	-0.0080
22 Water Supply	-0.0004	-0.0001	-0.0001	-0.0001	-0.0008	-0.0009	-0.0011	-0.0021	-0.0005	-0.0010	-0.0001	-0.0006	-0.0009	-0.0007	-0.0005	-0.0009	-0.0016	-0.0022	-0.0001	-0.0001	-0.0003	0.9994	-0.0002	-0.0002	-0.0005	-0.0001	-0.0007	-0.0012	-0.0055
23 Building Construction and Machinery Rental	0.0000	-0.0019	0.0000	0.0000	0.0000	-0.0008	-0.0004	-0.0005	-0.0002	-0.0002	-0.0001	-0.0003	-0.0003	-0.0001	-0.0002	-0.0004	-0.0003	-0.0002	0.0000	-0.0002	0.0000	0.0000	0.9947	0.0000	-0.0002	-0.0001	-0.0071	-0.0066	-0.0038
24 Public Works Construction	-0.0029	-0.0439	-0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-0.0104	-0.0018	-0.0071	0.0000	0.9273	0.0000	-0.0004	-0.0218	-0.0006	0.0000
25 Commerce	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000
26 Transportation (Road, Water, Air)	-0.0109	-0.0436	-0.0540	-0.0199	-0.0022	-0.0239	-0.0195	-0.0216	-0.0263	-0.0258	-0.0136	-0.0290	-0.0247	-0.0380	-0.0214	-0.0207	-0.0152	-0.0177	0.0000	-0.0025	-0.0042	-0.0032	-0.0001	0.0000	-0.0456	0.9852	-0.0238	-0.0122	-0.0740
27 Additional Transportation Services (Storage, Handling)	0.0000	-0.1019	0.0000	0.0000	-0.0054	0.0000	-0.0003	-0.0009	0.0000	-0.0001	0.0000	0.0000	0.0000	-0.0004	-0.0005	0.0000	-0.0006	-0.0005	-0.0113	0.0000	-0.0031	0.0000	0.0000	0.0000	-0.0058	-0.1026	0.9916	-0.0010	-0.0032
28 Services to Companies (Finance, RE,Health)	-0.0242	-0.0639	-0.0394	-0.0492	-0.0226	-0.0629	-0.0724	-0.0410	-0.0767	-0.1020	-0.0198	-0.1069	-0.0853	-0.0870	-0.0532	-0.0765	-0.0583	-0.0820	-0.0021	-0.0679	-0.2433	-0.1886	-0.0354	-0.0379	-0.1778	-0.1750	-0.4046	0.7933	-0.3513
Wages and Salaries	-0.1708	-0.0719	-0.0141	-0.0380	-0.1817	-0.0792	-0.1555	-0.1980	-0.1011	-0.0948	-0.0285	-0.1038	-0.1527	-0.1023	-0.0666	-0.1075	-0.1239	-0.0892	-0.0791	-0.0926	-0.0615	-0.1663	-0.0967	-0.0612	-0.3279	-0.0792	-0.2632	-0.2740	0.9889

Source: Thesis Calculations